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# Swirl and Helical Bend Regulator/Concentrator for Storm and Combined Sewer Overflow Control

by

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16. ABSTRACT

Swirl and helical bend devices were studied for three years at Lancaster, PA, and West Roxbury in Boston, MA. At Lancaster the study included:

- a full-scale swirl regulator/solids concentrator (SRC) for combined sewer overflow (CSO) control (24-ft (7.3-m) diameter) and
- a swirl degritter for SRC foul underflow (8-ft (2.4-m) diameter).

At West Roxbury the study included:

- a pilot-scale SRC for separate urban stormwater treatment (10.5-ft (3.2-m) diameter) and
- a pilot-scale helical bend regulator/solids concentrator (HBRC) for separate urban stormwater treatment (60-ft (18.3-m) long).

Data from the Lancaster facility indicated that the SRC is an efficient treatment device to remove heavier or "first flush"-related suspended solids and grit. Treatment efficiencies usually exceeded 60% for flows exceeding 20 cfs (566 l/s). The swirl degritter did not function properly due to clogging of the bottom hopper apex.

At West Roxbury, efficiencies were low for both units and appear to be related to very low settling velocities of the suspended solids.

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# FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment for public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research, a most vital communications link between the researcher and the user community.

The deleterious effects of storm sewer discharges and combined sewer overflows upon the nation's waterways have become of increasing concern in recent times. Efforts to alleviate the problem depend in part upon the development of integrated technologies involving non-structural best management practices with structural storage and treatment concepts.

This report presents the summary results of a three year field-oriented data collection and analysis effort aimed at evaluating the feasibility and efficiency of flow regulator/concentrators for control of urban stormwater pollution. The practice of designing regulators solely for flow rate control or diversion of combined wastewaters to treatment plants and overflow to receiving waters has proved costly and inefficient. Sewer system management which emphasizes the dual function of qualitative and quantitative control of storm induced water pollution has proved highly cost-effective under several separate evaluation studies. The use of the Swirl Regulator/Concentrator and Helical Bend Regulator for control of both separately sewered urban stormwater and combined sewer overflows (CSO's) have resulted in removal efficiencies comparable to those achieved through the use of conventional settling tanks.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

# ABSTRACT

This report summarizes the results of a three year study on the applicability of full scale Swirl Regulator/Concentrators and Helical Bend Regulators for qualitative and quantitative control of pollutant loads released through storm discharges and combined sewer overflows (CSO). Two separate studies were incorporated into this report; 1) an examination of the feasibility of using the Swirl Regulator/Solids Separator and Helical Bend Regulator for wastewater treatment of a separate storm sewer serving an urbanized area in West Roxbury, Ma., and 2) a post construction evaluation of an existing U.S. Environmental Protection Agency/City of Lancaster, Pa. Swirl Regulator/Concentrator and Swirl Degritter complex located in Lancaster, Pa. for the abatement of CSO pollution. This report does summarize earlier design/construction details of the demonstration facility at Lancaster.

The West Roxbury, Ma. Swirl, Helical Bend complex evaluation was divided into three separate phases. The first phase involved site inspection and runoff flow evaluation. Phase two included design, fabrication and installation of the two fullscale treatment devices while the monitoring, evaluation, data reduction and comparative assessments were included in phase three. Detailed site inspections, low level flow monitoring effort and detailed computer modeling to ascertain typical runoff flows resulted in the design of a 10.5 ft (3.2 m) diameter Swirl Regulator/Concentrator and 60 ft (18.3 m) long Helical Bend Regulator with design flows each of 6 cfs (173 l/s) and maximum capacity of 12 cfs or (346 l/s). Foul sewer underflow from each unit was regulated by a Hydro-Brake at a cfs of 3% of the design flow or 0.18 cfs or (.85 l/s). The second phase involved the fabrication and installation of the units near an outlet of a separate storm sewered 160 acre urbanized area. The stormwater flow at the outlet was divided and input into Swirl and Helical Bend Regulator/Concentrators constructed side-by-side.

In the third phase of work, the two treatment units were monitored during a 22 month period for approximately 15 separate storm events covering a wide range of antecedent dry conditions, rainfall intensities and durations. This phase included 1) an assessment of the hydraulic influent/foul sewer waste stream characteristics 2) testing the feasibility of foul sewer discharge to an adjacent sanitary sewer for removal of waste stream effluents, and 3) assessment of the influent,effluent and foul stream characteristics from both devices with respect to COD and solids.

Data reduction and desk-top analytical efforts resulted in a comparative assessment of pollutant removal effectiveness of the two devices. Suspended solids removal efficiencies observed for the units ranged between 5% - 35% depending on the characteristics of the event sampled.

The Lancaster, Pa., study involved three phases of work for demonstrating the applicability of the full scale swirl concept for CSO control. Planning, design and construction of the facility was completed in the first phase of work. A 24 ft (7.3 m) diameter Swirl Regulator/Concentrator was constructed along with an 8 ft (2.4 m) diameter Swirl Degritter. Swirl Regulator/Concentrator was designed for a design of 40 cfs (1132 l/s) with capacity for handling 90 cfs (2547 l/s). The Swirl Degritter was designed for a discharge of 1.5 cfs (42.5 l/s). A Hydro-Brake limited foul sewer underflow from the Swirl Regulator/Concentrator to the Swirl Degritter at a discharge level of 1.2 cfs (34 l/s).

The initial performance evaluation was then conducted in the second phase of work. (1978-1979) Many instrumentation problems were encountered. Instrumentation and performance monitoring equipment were modified and a second evaluation period (1980-1981) was conducted during the third phase. Final Report preparation was part of the final phase.

Monitoring results during the initial evaluation period (1978-1979) indicated negligible CSO solids treatment efficiency for the Swirl Regulator/Concentrator. After the existing monitoring equipment was modified and new state of the art sampling equipment installed, results of the second evaluation period (1980-1981) indicated that the Swirl Regulator/Concentrator is an efficient treatment device for removal of "first-flush" related suspended and settleable solids. Treatment efficiencies observed exceeded 60% for flows exceeding 20 cfs (566 l/s). Swirl Degritter performance results were inconclusive.

The West Roxbury (Boston), Ma. demonstration project was completed in fulfillment of Grant No. S805975 by Environmental Design & Planning, Inc. under joint sponsorship of the U.S. Environmental Protection Agency (U.S. EPA), the Division of Water Pollution Control (DWPC), State of Massachusetts, the Department of Environmental Quality Engineering, (DEQE) State of Massachusetts, with the Boston Water & Sewer Commission (BW&SC), Boston, Massachusetts and the Metropolitan District Commission (MDC), Boston, Massachusetts.

The first two phases of the Lancaster, Pa. demonstration project were completed by Huth Engineering, Lancaster, Pa., in fulfillment of Grant No. S-802219 under joint sponsorship of the

U.S. Environmental Protection Agency and the City of Lancaster, and the final phase including report preparation was by Environmental Design and Planning, Inc.

This report covers the period March 1979 to December 1981 and work was completed January 1982.

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## ABBREVIATIONS AND SYMBOLS

### Abbreviations

| | |
|---|---|
| cc | cubic centimeter |
| cm | centimeter |
| cm/sec | centimeter per second |
| cfs | cubic feet per second |
| cu yds | cubic yards |
| ft | feet |
| ft$^3$ | cubic feet |
| g | gram |
| gal | gallon |
| g/cc | grams per cubic centimeter |
| g/l | grams per liter |
| g/s | grams per second |
| gal/ft$^2$/day | gallons per square foot per day |
| gpm | gallons per minute |
| gpm/ft$^2$ | gallons per minute per square foot |
| ha | hectare |
| hr | hour |
| in./hr | inch per hour |
| l | liter |
| l/s | liter per second |
| lpm | liter per minute |
| l/s/m$^2$ | liter per second per square meter |
| lb/ft$^2$ | pounds per square foot |
| lb/ft$^3$ | pounds per cubic foot |
| lb/min | pounds per minute |
| kg | kilogram |
| kg/m$^2$ | kilogram per square meter |
| kg/min | kilogram per minute |
| km | kilometer |
| km/ha | kilometer per hectare |
| m | meter |
| m$^3$ | cubic meter |
| m$^3$/min | cubic meter per minute |
| m$^3$/sec | cubic meter per second |
| mg/l | milligram per liter |
| mgal | million gallons |
| mgd | million gallons per day |
| ml/l | milliliter per liter |
| rpm | revolutions per minute |
| sg | specific gravity |

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## Symbols

| | |
|---|---|
| $b_2$ | Swirl Concentrator Offset, Primary Gutter |
| BOD | Biochemical Oxygen Demand |
| BMP | Best Management Practices |
| C | Clear Overflow Concentration |
| CF | Clear Overflow Concentration Factor |
| CM | Clear Overflow Mass Rate |
| COD | Chemical Oxygen Demand |
| CSO | Combined Sewer Overflows |
| $D_1$ | Swirl Concentrator Inlet Dimension |
| $D_2$ | Swirl Concentrator Chamber Diameter |
| $D_3$ | Swirl Concentrator Scum Ring Diameter |
| $D_4$ | Swirl Concentrator Clearwater Weir Diameter |
| $D_1$* | Swirl Degritter Inlet Dimension |
| $D_2$* | Swirl Concentrator Chamber Diameter |
| $D_3$* | Swirl Degritter Clearwater Weir Diameter |
| D.L. | Diversion Level |
| E | Efficiency |
| ffc | Foul Flow Concentration Factor |
| FC | Foul Flow Concentration |
| FM | Foul Flow Mass Rate |
| H1 | Swirl Concentrator Height to Clearwater Weir |
| h1 | Swirl Concentrator Depth of Clearwater Weir |
| h2 | Swirl Concentrator Depth of Floatable Trap |
| $H_1$ * | Swirl Degritter Depth to Weir |
| $H_2$ * | Swirl Degritter Depth of Weir |
| $H_3$ * | Swirl Degritter Depth of Cone |
| I | Influent Concentrator |
| IM | Influent Mass Rate |
| Q | Discharge |
| $R_1$ | Swirl Concentrator Primary Gutter Radius |
| $R_2$ | Swirl Concentrator Primary Gutter Radius |
| $R_3$ | Swirl Concentrator Secondary Gutter Radius |
| $R_4$ | Swirl Concentrator Secondary Gutter Radius |
| $R_5$ | Swirl Concentrator Secondary Gutter Radius |
| RR | Removal Rate |
| $S_1$ | Swirl with Diameter 1 |
| $S_2$ | Swirl with Diameter 2 |
| S.L. | Swirl Level |
| % | Percent |
| vs | Versus |

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FINAL

# CHAPTER 1

# INTRODUCTION

## 1.1 Foreword

Background information is presented in Section 1.2 describing the urban runoff problem and the control of urban runoff. Section 1.3 discusses the need for improved runoff control technology such as the Swirl and Helical Bend regulator/concentrators. A general review of the Lancaster and West Roxbury Facilities is provided in sections 1.4 and 1.5 respectively, including each project's goals and objectives. The purpose of this report is presented in section 1.6 and a reader's guide to the report is provided in section 1.7. Detailed descriptions of the operational units and additional background material not given in this Chapter are provided in Chapter 4.

## 1.2 BACKGROUND

### THE URBAN RUNOFF PROBLEM

Three major types of discharges constitute the urban runoff pollution problem including: combined sewer overflows from predominantly older cities, separate storm drainage from newly developed areas, and diffuse nonpoint overland flow encompassing pollution loads from all types of land use activities.

A combined sewer is a sewer which accepts both domestic sewage and stormwater flow. These sewers feed both stormwater and sewage to the treatment plant up to its design limit. When wet weather flows exceed this limit, combined sewer overflow (CSO) occurs, resulting in degradation to receiving water quality due to washout of sewage and contaminated runoff.

Untreated storm overflows from combined (storm and sanitary) sewers are a substantial water pollution source during wetweather periods. There are roughly 15,000 to 18,000 combined sewer overflow points in the United States that can equal 40 to 80 percent of the total organic load from municipalities during wet-weather flow periods. It has been estimated that, on a national level the expenditure for combined sewer overflow pollution abatement would be $25 billion.(1)

Erosion of hillsides and construction sites caused by rainfall can produce extremely high concentrations of inorganic solids, frequently several times higher than those in municipal sewage. Unauthorized or intentional cross-connections with sanitary or industrial sewers are common. Diffuse non-point source pollution from overland runoff and drainage is extremely difficult to effectively manage and control. Best Management Practices (BMP) of a non-structural nature can often be effective to help eliminate the problems by controlling the original sources of pollutants.

Within the past 20 years, it has been recognized that waters discharged from separate storm sewers contain pollutants. Even without the addition of sanitary and industrial wastewaters, storm sewer discharges are usually high in suspended solids (TSS) and on occasion, may have Biochemcial Oxygen Demand (BOD) concentrations approaching those in municipal sewage. Rain falling on an urban area picks up pollutants from the air, dusty roofs, littered and dirty streets and sidewalks, traffic byproducts (tire residuals/vehicular exhaust), galvanic corrosion particulates, and chemicals applied for fertilization, control of ice, rodents, insects and weeds.

The stormwater runoff problem is a direct result of urban growth and development. Roughly eighty percent of the population of the United States is now urbanized with the process of urbanization proceeding at an estimated rate of about 1,500 square miles (3900 sq km) per year. For years discharges from stormwater drainage systems were considered to be non-polluting and therefore were ducted to the nearest available water course on the basis of convenience and cost. Impacts from storm drainage systems are often more severe than municipal discharges in a given area.

In storm sewers, there is a tendency for solids to settle out during the latter storm stages as the flow tapers off and velocities are reduced. Also, large separate sewer systems may have relief points that allow some surcharged sanitary sewers, even on rare dry weather occasions, to overflow into the storm sewers. The solids in the municipal sewage overflows may accumulate in storm sewers under these conditions and contribute to a "first-flush" effect in storm sewers. A similar situation exists when storm sewers have illicit direct industrial and sanitary connections.

The accumulated solids deposits may contain grease and other organic matter undergoing decay. When the sewer overflow increases sharply during a storm, this solid matter which will exert a high organic loading will be discharged. Depending on the sewer system, the rainfall intensity and the number of antecedent dry days, a "first-flush" effect may result. If it does occur, it may last for a few minutes or even hours. Solids scoured from the upper reaches of the large system may take a long time to reach a distant overflow point. BOD concentrations during these periods may often exceed those of the normal untreated dry weather wastewater.

## CONTROL OF URBAN RUNOFF

The control of combined and storm sewer pollution loadings is one of the more difficult and expensive problems the Nation faces in the abatement of pollution for enhancing the quality of its rivers, lakes and streams. During the next decade or so, it is expected that billions of dollars may be spent in the United States to combat the degradation of water bodies by pollutants released through storm discharges and combined sewer overflows. The difficulties and the need for solutions to urban stormwater pollution have spawned over the past decade a major research and development effort both in the United States and in other nations around the world. The U.S. EPA, Storm & Combined Sewer Research group has engaged in multiple research and development programs and investigating to identify, control and correct the causes of known problems relating to these storm occurrences.

U.S. EPA has developed over the last decade a number of different treatment strategies for abating urban runoff pollution. Physical treatment alternatives are the most promising class of techniques that have resulted from this research effort. Physical treatment alternatives are primarily applied for floatable, suspended and settleable solids removal and their associated pollutants from wastestreams, and are of particular importance to storm and combined sewer overflow treatment. Removal of these contaminants minimally enhances visual recreational potential of surface waters. Further treatment for colloidal and dissolved pollutants contained in urban runoff may never be feasible due to the inordinate costs of handling large volumes.

Conventional physical treatment alternatives for stormwater and combined sewer control typically involve expensive highly structural measures such as detention/sedimentation basins (high capital costs/moderate operational costs) or filtration/screening facilities (moderate first costs/ high operational costs). U.S. EPA sought through research new inexpensive combination of methods with low operational costs providing comparable solids removal efficiencies.

There is no "best" technological alternative for all CSO problems. The most efficient control procedure is highly dependent upon the individual problem. Some of the more feasible alternatives are street sweeping, periodic flushing of sewers, cleaning of catchbasins, micro-screens for solids removal, in-line and/or off-line storage of storm flow and replacement of the older combined sewers with newer separated sewers. However, many of these alternatives are costly and require substantial maintenance. Also, many of these alternatives control either the quality or the quantity of CSO, not both. The most recent control philosophy has been referred to as the "two Q" concept where the emphasis is on both the quality and quantity of the combined sewage overflow.

Since the regulator in the combined sewer system is the overflow point and is a logical point of control, the practice in the United States of designing regulators exclusively for flow-rate control or diversion of combined wastewaters to the treatment plant and overflow to receiving waters is reconsidered as part of the "two Q" concept. Sewer system management that emphasizes the dual function of combined sewer overflow regulator facilities for improving overflow quality will pay significant dividends. The dual function is concentration of wastewater solids to the sanitary interceptor, and diversion of excess storm flow to the outfall.

## 1.3 The Need for Improved Regulators

In considering wet weather water pollution abatement, attention must first be directed to control of the existing combined sewerage system and replacement (or stricter maintenance) of faulty regulators. Consulting and municipal engineers will agree that regulator mechanical failures and blockages persist at the overflow or diversion points resulting in unnecessary bypassing, which is also a problem during dry weather. Malfunctioning overflow structures, both of the static and dynamic varieties, are major contributors to the overall water pollution problem.

Sewer system management that emphasizes the dual function of combined sewer overflow regulators for improving overflow quality by concentrating wastewater solids to the sanitary interceptor and diverting excess storm flow to receiving water body has been recognized as a practical, efficient method to reduce receiving water pollution. A new class of solids separation devices have emerged from research seeking to improve combined sewer regulators. These devices are termed secondary flow solids separators. These devices can either operate as a regulator with capacity to provide treatment during wet weather or alternatively, can be viewed as strictly off-line treatment units. The Swirl and Helical Bend regulators are two such devices. These new devices can be used to remove floatable, settleable, suspended solids and their associated pollutants from wastestreams and are particularly important to stormwater and CSO treatment. The Swirl also has application for industrial waste treatment requiring solids separation.

In the mid 70's U.S. EPA also perceived a need to develop and have reserve of control hardware for urban stormwater pollution from separate storm drainage, and to effectively reduce the associated high cost implications for conventional storage tanks. It was felt that the Swirl/Helical type regulators previously thought of for application only to combined sewer overflow could be installed on separate storm drains before discharge. The resultant concentrate can be stored in relatively small tanks since concentrate flow is only a few percent of total flow. Stored concentrate can later be directed to the sanitary sewer for subsequent treatment during low flow or dry weather periods or if capacity is available in the sanitary system, the concentrate may be diverted to it without storage. This method of stormwater control would be cheaper in many instances than building huge holding reservoirs, and it offers a feasible approach to the treatment of separately sewered urban stormwater.

## SWIRL REGULATOR CONCENTRATOR

The Swirl Regulator/Concentrator is of simple annular-shaped construction and requires no moving parts. It provides the dual function, regulating flow by a central circular weir spillway, while simultaneously treating influent wastewater by swirl action which imparts solids/liquid separation. (See Figure 1.)

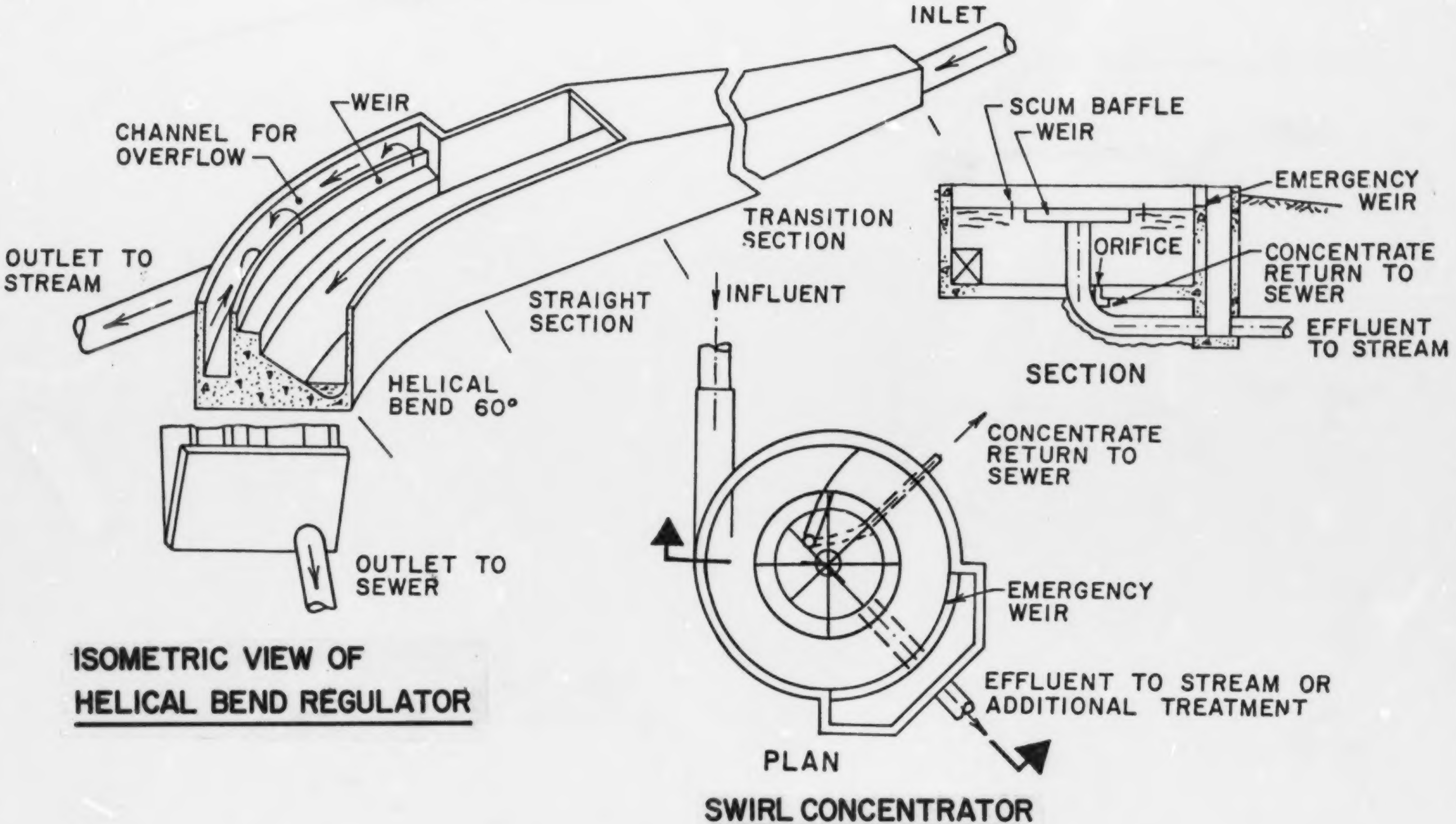
INLET
WEIR
CHANNEL FOR OVERFLOW
OUTLET TO STREAM
TRANSITION SECTION
STRAIGHT SECTION
HELICAL BEND 60°
OUTLET TO SEWER
ISOMETRIC VIEW OF HELICAL BEND REGULATOR
SCUM BAFFLE
WEIR
EMERGENCY WEIR
ORIFICE
CONCENTRATE RETURN TO SEWER
EFFLUENT TO STREAM
SECTION
INFLUENT
CONCENTRATE RETURN TO SEWER
EMERGENCY WEIR
EFFLUENT TO STREAM OR ADDITIONAL TREATMENT
PLAN
SWIRL CONCENTRATOR

Figure 1. Helical Bend and Swirl Concentrator.

The combined sewage flow is fed to the unit tangentially. A slow circular motion is induced by the flow's kinetic energy and separation of the larger, denser solids occurs at the bottom of the swirl. This concentrated flow is then transported either to a pump station for conveyance, or directly to a sewage treatment plant. Cleaner flow at the top of the circular tank overflows to a discharge point, reducing the amount of flow requiring further treatment.

Investigation of this mechanism for CSO control has been extensive. There have been a number of studies on the applicability of secondary flow mechanisms for abatement of combined sewer overflow problems. These include studies performed by the American Public Works Association, (APWA) La Salle Hydraulic Laboratory, Ltd. and the University of Florida. However, the initial vortex concept was first studied in Bristol, England in the early 1960's.

Studies were carried out in Bristol for the purpose of determining the hydraulic and performance characteristics of the vortex mechanism. (2) It was found that this mechanism would concentrate combined sewage solids from the liquid portion of the flow and that the majority of the solids in the flow could be collected in an "underflow foul sewer" for conveyance to a sewage treatment plant. Further discussion of this research is provided in Chapter 4, section 4.7. At this point U.S. EPA decided to investigate this "vortex" mechanism for use in combined sewer overflows in the United States. The resultant investigation, which was conducted by the APWA initially consisted of modeling the required hydraulic and mathematics conditions for the optimal concentration of solids from the applied flow.

The La Salle Hydraulic Laboratory, Ltd. (Laboratorie D'Hydraulique), LaSalle, Quebec, Canada, conducted hydraulic modeling studies and the General Electric Company, Re-Entry and Environmental Sytems Division, Philadelphia, conducted mathematical modeling for the APWA study. Both modeling efforts were combined in a report published by U.S. EPA in September 1972 (3).

The Swirl Concentrator model in the hydraulic study was 36 in. (91.4 cm) in diameter, 40 in. (101.6 cm) high and made of 1/2 in. (1.3 cm) plexiglass. The inflow to the unit was seeded with a known concentration of gilsonite to simulate combined sewerage. During the modeling studies, it was determined that agitation caused by the vortex mechanism provided for mixing of the solids which resulted in reduced efficiencies for solids concentration. Therefore a flow deflector was constructed in the model to prevent full vortex motion, resulting in a gentle "swirling" motion which improved the efficiency of solids concentration.

Various alterations to the swirl model were tested in order to optimize performance. The tested variables included inlet aperature size, foul outlet location, inlet slope, gutter depth and configuration, weir diameter and the floatables trap configuration. After consideration of these variables in the unit's performance, the study arrived at a recommended configuration and design procedure.

At this point U.S. EPA desired to test the Swirl Concentrator in a full-scale mode. The City of Lancaster, Pennsylvania worked with U.S. EPA to institute the first major full-scale Swirl Regulator/Concentrator for CSO control. Other much smaller installations were also being built and tested during this period and are discussed later.

A supplement to this report was published in July 1974 entitled "Relationship Between Diameter and Height for the Design of a Swirl Concentrator as a Combined Sewer Overflow Regulator." (4) This report augmented the original hydraulic modeling studies at LaSalle Hydraulic Laboratory, Ltd. The purpose of this report was to further develop the necessary design parameters of the Swirl Regulator for maximum solids concentration efficiency. Various geometric modification curves were developed to facilitate design when head or existing system constraints exist. This study has proven very helpful for the design of Swirl Regulator/Concentrators and was utilized in the design of the Swirl unit for the City of Lancaster.

During the initial modeling of the swirl concept, it was noted that solids of particular sizes or specific gravities were more effectively separated from the flow. Therefore, it was logically deducted that the swirl concept could also be used as a mechanism for grit removal as well as for the concentration of CSO's. In June 1974 U.S. EPA published a report entitled "The Swirl Concentrator as a Grit Separator Device."(5) This report summarizes hydraulic studies undertaken to evaluate grit removal with a swirl unit, which were also performed at the LaSalle Hydraulic Laboratory, Ltd. Consequently, these hydraulic studies focused on the many variables in the swirl grit unit's design.

The University of Florida Department of Environmental Engineering Sciences completed a report entitled "Storm Water Management Model: Refinements, Testing and Decision-Making" in June 1973.(6) The goal of this study was to improve and update the EPA Storm Water Management Model (SWMM) by including urban erosion prediction, modeling of new treatment devices, monitoring of pollution sources and modeling pollution loading from large areas with flexibility. The computer model was programmed to predict runoff hydrographs and pollutographs during a storm event. The purpose was to predict quality and quantity of stormwater runoff in any area given the local characteristics. The model was tested in the Stevens Avenue Drainage District in the City of Lancaster, Pennsylvania where field measurements compared favorably with the predicted hydrographs and pollutographs. This modeling tool proved valuable in estimating the characteristics of the combined sewage to be treated by the Lancaster Swirl Regulator/Concentrator.

In addition to the full scale Swirl Degritter and Swirl Regulator/Concentrator for CSO control at the Lancaster facility there have been several pilot-type installations throughout the United States. The City of Denver, Colorado utilized a Swirl prototype for grit removal in the early 1970's (7). Syracuse, New York installed a 12 ft (3.6 m) diameter Swirl Regulator/Concentrator and subsequent operation indicated successful separation of CSO solids. (8) Rochester, New York installed and successfully tested a pilot Swirl Concentrator in series for CSO treatment.(9) Toronto, Ontario, Canada installed a pilot swirl primary separator which was tested for primary sedimentation of sanitary sewage.(10) The above pilot facilities generally were successful and supported the feasibility of the swirl concept in several various applications.

Helical Bend Flow Regulator - The Helical Bend flow regulator is based on the concept of using the secondary helical motion imparted to fluids at bends where a total angle of approximately 60 degrees is employed. (See Figure 1) Hydraulic model studies of this device, carried out at the University of Surrey, England, indicated that this is a feasible means of separating solids from the overflow. (11)

The basic structural features of significance in the Helical Bend are: a) the inlet from the entrance sewer section to the device; b) the transition section from the inlet to the expanded cross section of the straight-run section ahead of the bend; c) the overflow side weir and scum board, or so-called drip plate; and d) the foul outlet for the concentrated solids removal in the secondary flow pattern together with the means for controlling the amount of this underflow going to the treatment works.

The heavily polluted sewage is drawn to the inner wall. It then passes to a semicircular channel situated at a lower level leading the treatment plant. The proportion of the concentrated discharge will depend on the particular design. The overflow passes over a side weir for discharge to the receiving waters. Surface debris collects at the end of the chamber and passes over a short flume to join the sewer conveying the flow to the treatment plant.

The model study indicated that even the simplest application of the spiral flow separator will produce an inexpensive regulator that will be superior to many existing types. (11) It was also stated that further research is necessary to define the variables, the limits of applications and the actual limitations of the spiral flow regulator. A prototype Helical Bend regulator has been designed and constructed at Nantwhich, England.

A Helical Bend hydraulic model was constructed at the La Salle Hydraulic Laboratory. Configuration changes and internal auxiliary flow control and effluent improvement modifications, as well as detailed studies of the helical flow patterns developed and suspended solids removal efficiencies achieved, were studied. (12) As part of this effort, Mathematical model and computer simulation of the device was conducted by the General Electric Company.(12) The hydraulic model studies and the computer mathematical simulation of the Helical Bend combined sewer overflow regulator indicate that this "flash-method" of solids removal, without use of mechanical appurtenances, can produce excellent efficiences with reasonable size units in combined sewer systems.

The ultimate purpose of these studies was to correlate and confirm findings by both hydraulic and mathematical means and to develop design criteria which will enable engineers to utilize the helical flow principle for solids removal from combined sewer flows and to properly regulate the overflow of clarified wastewater to receiving waters or points of retention and/or treatment.

A design manual for secondary flow pollution control devices including Swirl Concentrator and the Helical Bend Regulator was recently prepared by APWA in cooperation with U.S. EPA (13). This report is meant to coalesce piece-meal reporting from the various research and demonstration projects into one unified document.

## 1.4 HISTORICAL BACKGROUND AND PURPOSE OF LANCASTER FACILITY

The City of Lancaster, Pa. experimented with a full scale swirl installation due to severe CSO problems and U.S. EPA's commitment to partially fund a demonstration project for the Swirl/Regulator Concentrator.

Following U.S. EPA's decision to use a relatively isolated drainage district within the City, a cooperative effort between both the City and the U.S. EPA resulted in the initiation of project design. Preliminary design of the Lancaster Swirl Project was completed by Meridian Engineering, Inc., Philadelphia, PA in 1972. (14) At that time the project was known as the Silo Project. The prototype swirl foul underflow containing the concentrated solids would be pumped to an interceptor for conveyance to the City's South Wastewater Treatment Plant (WWTP), with the clean overflow from the swirl stored in a large, aerated silo-shaped storage tank for release to the Conestoga River following chlorination. As an alternate, the overflow could be pumped back to the interceptor sewer during a dry period. This concept was not used due to the prohibitive cost of the silo construction.

In February 1974, Huth Engineers, Inc. of Lancaster, PA was retained by the City of Lancaster to initiate the design of the Swirl Regulator/Concentrator. A facilities layout and a schematic flow diagram of the project are shown in Figures 2 and 3, respectively. The new concept called for a prototype Swirl to receive the combined sewage with the foul outlet flow being controlled and directed to a second, smaller Swirl device for grit removal while the overflow from the larger Swirl Regulator/Concentrator unit would be discharged to the Conestoga River. The inclusion of the Swirl Degritter unit was for the purpose of preventing excessive wear due to grit particles in the raw sewage pumps which are downstream of the degritter clear effluent. The separated grit would be collected and weighed after each storm event to aid in determining the degritter's removal efficiency. A Discostrainer was also included to evaluate it for removing solids from the flow stream. The overflow from the Swirl Degritter would then be pumped to the interceptor sewer via the existing Stevens Avenue Pumping Station.

The 24 ft (7.3m) diameter dual-functioning Swirl Regulator/concentrator treats CSO from the Stevens Ave. District (one of the city's six overflow points to the Conestoga River). The 215 acre (88.5 ha) drainage area served is approximately 50% residential and 50% parklands and undeveloped fields.

The Swirl was designed to operate at 40 cfs (1.1 $m^3$/sec)with capacity to be surcharged to 90 cfs (2.6 $m^3$/sec). During dry weather sewage enters the Swirl and is directed along the floor gutters to the foul underflow outlet and then directly to the pumping station. A Swirl Degritter and grit handling system was constructed to remove grit from the foul underflow of the Swirl Concentrator before the underflow is pumped to the municipal sewage treatment plant.

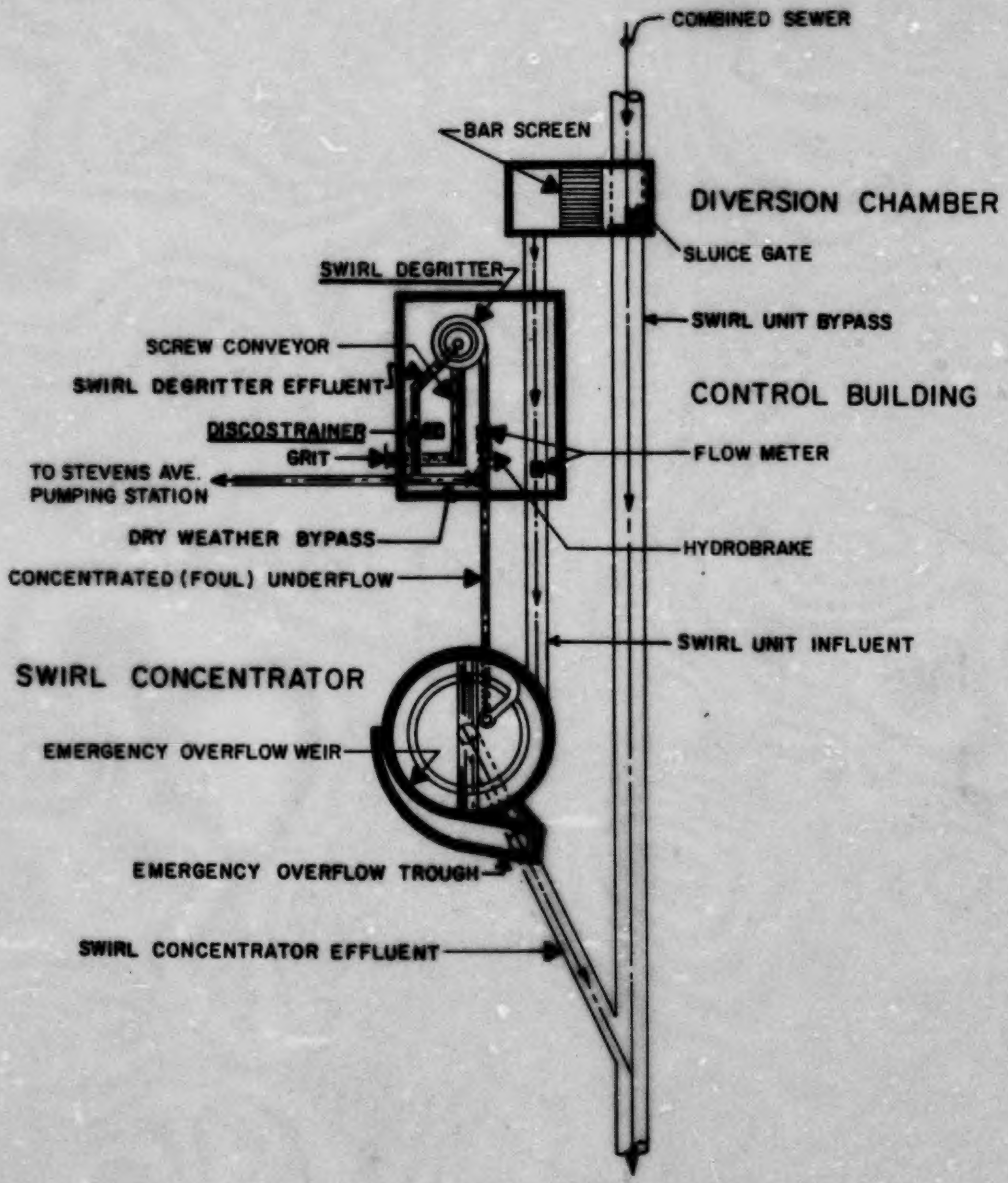
COMBINED SEWER
BAR SCREEN
DIVERSION CHAMBER
SLUICE GATE
SWIRL DEGRITTER
SWIRL UNIT BYPASS
SCREW CONVEYOR
SWIRL DEGRITTER EFFLUENT
CONTROL BUILDING
DISCOSTRAINER
GRIT
FLOW METER
TO STEVENS AVE. PUMPING STATION
DRY WEATHER BYPASS
HYDROBRAKE
CONCENTRATED (FOUL) UNDERFLOW
SWIRL UNIT INFLUENT
SWIRL CONCENTRATOR
EMERGENCY OVERFLOW WEIR
EMERGENCY OVERFLOW TROUGH
SWIRL CONCENTRATOR EFFLUENT
TO CONESTOGA RIVER

Figure 2. Lancaster Swirl Project facilities layout.

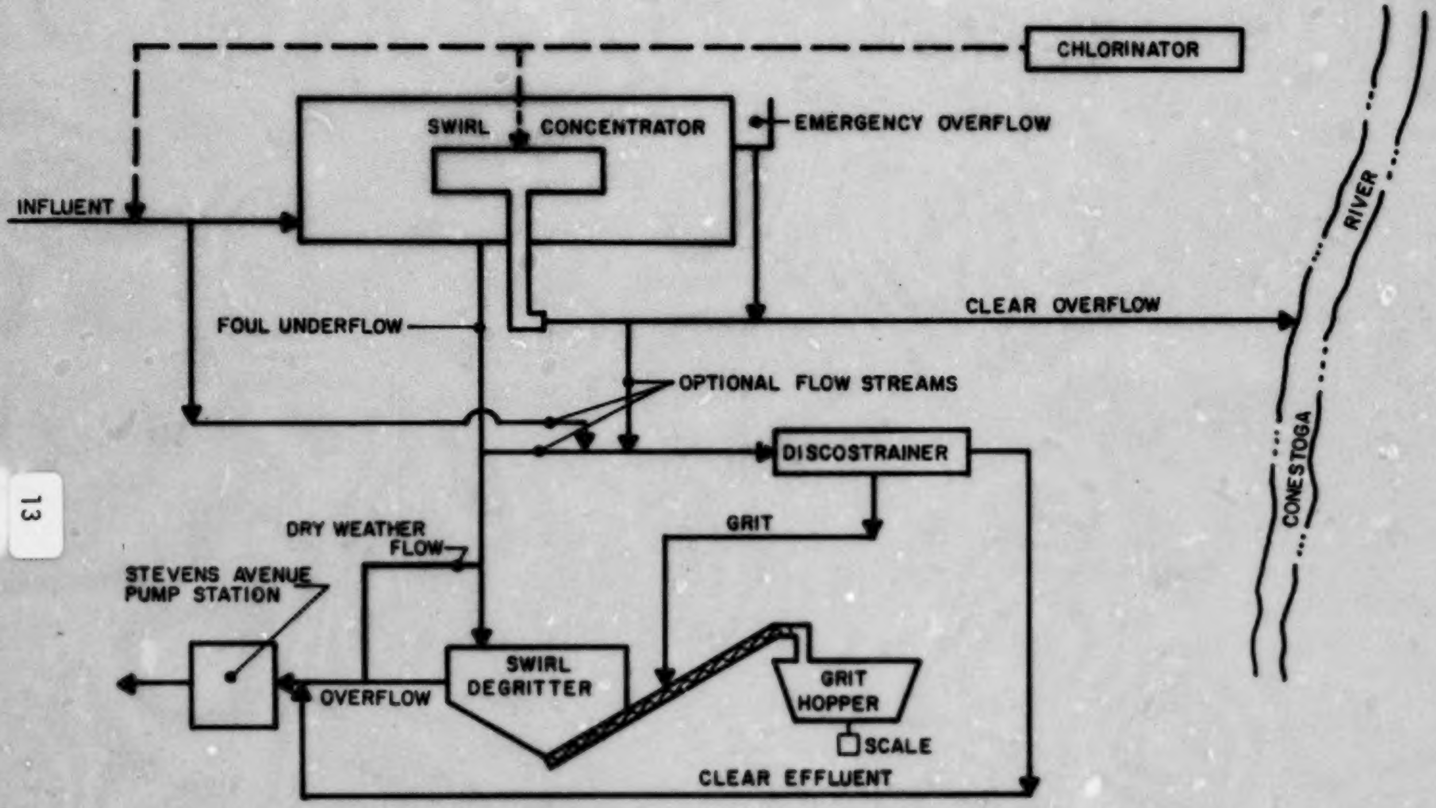
CHLORINATOR
SWIRL CONCENTRATOR
EMERGENCY OVERFLOW
INFLUENT
RIVER
CLEAR OVERFLOW
FOUL UNDERFLOW
OPTIONAL FLOW STREAMS
CONESTOGA
DISCOSTRAINER
GRIT
DRY WEATHER FLOW
STEVENS AVENUE PUMP STATION
SWIRL DEGRITTER
OVERFLOW
GRIT HOPPER
SCALE
CLEAR EFFLUENT

Figure 3. Schematic flow diagram of Lancaster Swirl Project.

The Huth project design concept called for a bar screen to protect downstream facility components from large debris. The Swirl facilities would be automatically activated when storm flow entered the swirl. A sonic level sensor would activate a sequence of valves to change the mode from dry to wet weather operation. All clear overflow would be chlorinated before discharge to the river. A chlorinated pipe extending over the clear overflow weir assembly can dose the effluent just before it is discharged. Flushing lines located on the side walls above the water line and under the floatables trap would wash deposits from the Swirl after each storm. The deposits would be washed to floor gutters and sent to treatment plant. An emergency overflow weir occupies one quadrant of the Swirl wall. The weir is 6 in. (15.2 cm) higher than the clear overflow weir and would provide an additional 19 ft (6 m) of weir length for flows that exceed the hydraulic capacity of the Swirl.

The final design of the project was completed by Huth Engineers, Inc. and approved by the U.S. EPA in November, 1976. Construction began in April 1977 and was completed in June 1978 with operation of the facility commencing shortly thereafter. Initial evaluation efforts in 1978 and 1979 were plauged by instrumentation problems.

Environmental Design & Planning, Inc., assumed responsibility for revamping critical elements of the facilities instrumentation, assisting the City in a further evaluation effort beginning in September, 1980 and lasting till July, 1981 and preparing the final report.

## PROJECT GOAL

The outlined project goals for the Lancaster Swirl Project are shown below. They are:

1. To successfully demonstrate the applicability of the full-scale swirl concept for use in the qualitative and quantitative control of CSO.

2. To determine the actual solids removal efficiency of an operating large-scale Swirl Regulator/Concentrator.

3. To demonstrate the efficiency and applicability of a Swirl Degritter in a CSO control installation.

4. To develop a background of cost and design experience for use in future installations. This includes noting any particular scale-up or design problems encountered.

## 1.5 HISTORICAL BACKGROUND AND PURPOSE OF WEST ROXBURY FACILITY

During the mid 1970's the Swirl Regulator/Concentrator was being examined by U.S. EPA and others as a suitable compact device for removing solids and particulate material from combined sewer overflows and primary treatment for grit separation at treatment works. The performance of the device was believed to be good and extremely economical. It was considered (and still is) as a viable control option in a number of combined sewer management studies throughout the country. The swirl had yet to be tried for removing pollutants from a separate storm sewered area.

The generation of operational experience using the Helical Bend regulator was still in its infancy. The full-scale field demonstration of the Helical Bend regulator had yet to be conducted. It was felt in the mid 70's that non-point control would soon move into the implementation phases for a number of areas throughout the country. Thus, it was deemed important to the federal government at that time to demonstrate the field feasibility of using Swirl and Helical Bend regulators to handle storm sewer emissions. The aim of the West Roxbury project was to determine the effectiveness of a full-scale installation using both devices for removing storm sewer pollutant emission loadings.

A plot plan of the West Roxbury, Boston research and demonstration facility is shown in Figure 4. Discharge from 160 acres (65 ha) of separated storm sewer system enters the site through an 87 in. (2.2m) reinforced concrete pipe (RCP) which connects into a 120 in. (3.05 m) conduit discharging to the Charles River 1000 ft (305 m) downstream. Storm drainage is diverted by gravity into the site and to the two units. Flow is split evenly to the two units by motor-driven bottom opening sluice gates. In the second mode of operation, sewage from a 27 in. (.68 m) sanitary trunk sewer (with severe inflow problems) is pumped over the 120 in. (3.05 m) drain and mixed with incoming storm drainage to simulate combined sewer overflow conditions.

Clear water discharge from the 10.5 ft (3.2 m) diameter Swirl drains by gravity into the 120 in. (3.m) reinforced concrete pipe. The foul sewer drains from the unit and is discharged by gravity into the foul sump tank. Discharge in the foul sewer underflow is limited to 3% of the design influent. The design flow is 6 cfs (170 l/s) with a maximum flow of 12 cfs (340 l/s) and a 0.18 cfs (5 l/s) underflow. The West Roxbury Facility is described in more detail in Chapters 6,8,10 and 13 of this report.

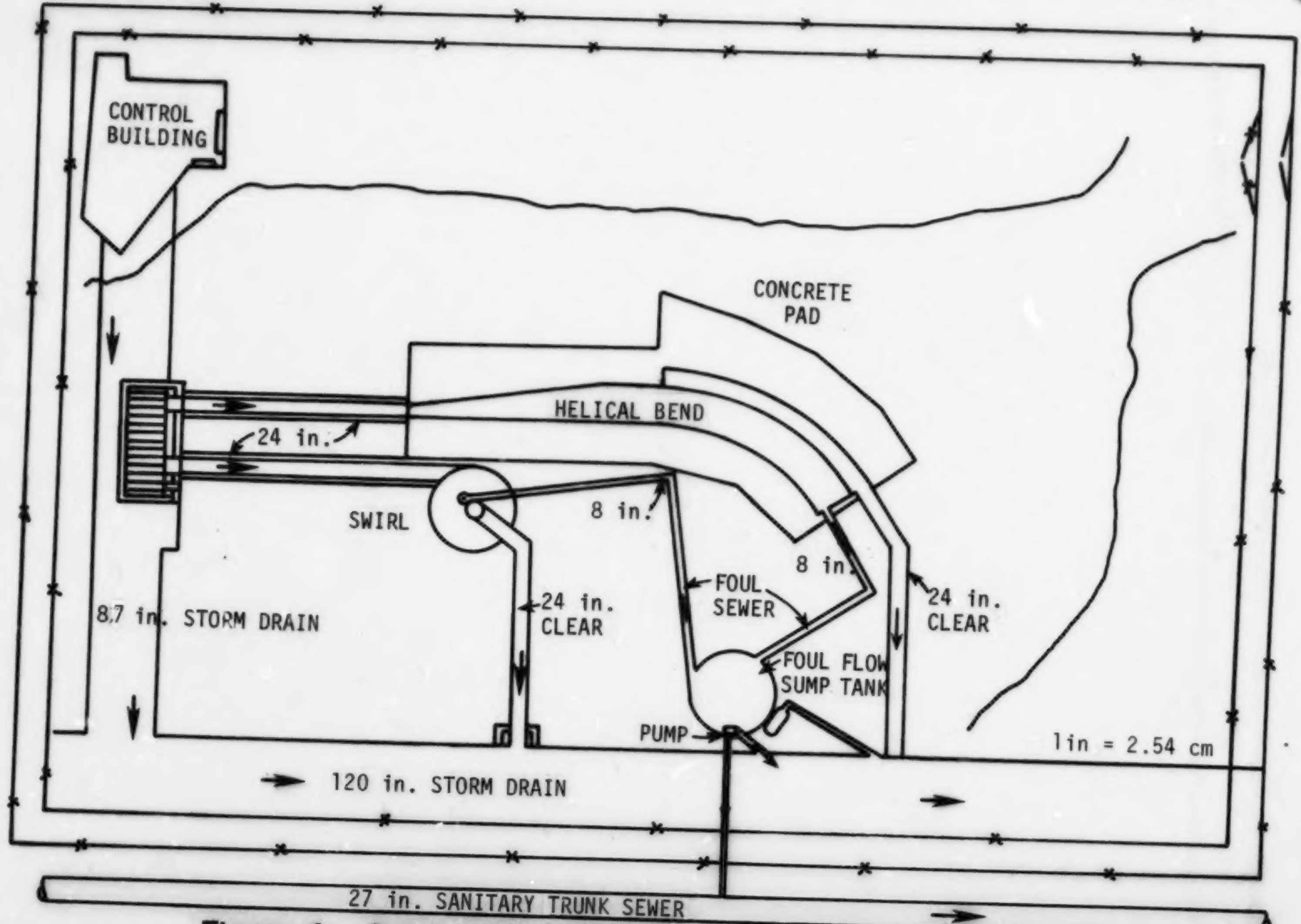
CONTROL BUILDING
CONCRETE PAD
HELICAL BEND
24 in.
SWIRL
8 in.
8 in.
FOUL SEWER
24 in. CLEAR
24 in. CLEAR
FOUL FLOW SUMP TANK
8.7 in. STORM DRAIN
PUMP
1in = 2.54 cm
120 in. STORM DRAIN
27 in. SANITARY TRUNK SEWER

Figure 4. Swirl/Helical Bend site plan, W. Roxbury Project.

PROJECT GOALS AND OBJECTIVE: The envisioned project was divided into three separate phases. The first phase dealt with detailed site inspections, low level flow monitoring efforts and detailed computer modeling to ascertain typical runoff flows for the design and construction phase. In the second phase of work, Swirl and Helical Bend Regulator/Concentrators were designed, fabricated and installed near the outlet of a separate storm sewered urbanized area. The flow at the outlet was divided and inputted into the two units constructed side by side. In the third phase of work, the two treatment units were monitored during a 12 month period for approximately 15 separate storm events covering a wide range of antecedent dry conditions, rainfall intensity and duration. A comparative assessment of the two units were made from these results.

The objectives of the project are as follows:

1) To design, construct, and install a Swirl and Helical Bend regulator operating on storm sewer discharged from a residential area for a 12 month period (15 storm events).

2) To test the operational pollutant reduction performance of a Swirl and Helical Bend regulator on a storm drainage discharge from a residential area.

3) To assess the hydraulic influent and effluent/foul sewer waste stream characteristics for various meteorological events of the two treatment devices.

4) To test the feasibility of foul sewer discharge to an adjacent sanitary sewer for the removal of waste stream effluents over an extended period.

### 1.6 Purpose of Report

The intended purpose of this report is to provide the user-community with a synopsis of the information available on the control of urban runoff pollution using secondary flow separation technologies. This report references various publications available on the abatement of stormwater runoff pollution in urbanized areas. A documentation of the results of the evaluation of stormwater regulator/concentrators is provided. Emphasis is placed on the methods of analysis and performance results of the two primary full scale facilities at Lancaster, Pa. and West Roxbury, Ma.

## 1.7 Report Coordinates

This report contains fifteen chapters. Summary conclusions and recommendations are presented in chapters 2 and 3. The remaining chapters can be classified under the heading of Process Description, Facility Description and Facility Evaluation. Table 1 lists the major groupings and their relevant chapters. Chapter 4 includes control process descriptions andhistories for the swirl concentrator, swirl degritter, swirl primary separator, dynamic separator and helical bend. Chapters 5 through 10 provide study area descriptions, design and construction of the Lancaster and West Roxbury facilities respectively. Evaluation methods and results for each facility are discussed in Chapters 11 through 13, respectively.

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## TABLE 1

## OUTLINE OF REPORT

A. Process Description

| Chapter | Title |
|---|---|
| 4 | Process Descriptions/History |

B. Facility Description

| Chapter | Title |
|---|---|
| 5 | Study Area Description - Lancaster |
| 6 | Study Area Description - W. Roxbury |
| 7 | Design - Lancaster |
| 8 | Design - W. Roxbury |
| 9 | Construction - Lancaster |
| 10 | Construction - W. Roxbury |

C. Facility Evaluation

| Chapter | Title |
|---|---|
| 11 | Evaluation - Methods |
| 12 | Evaluation - Results - Lancaster |
| 13 | Evaluation - Results - West Roxbury |

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# CHAPTER 2

# CONCLUSIONS

Conclusions derived from this investigation are divided into two road categories including: technical solids removal performance conclusions, instrumentation and sampling technique conclusions.

## A. Technical Performance Conclusions

### Lancaster

1. The Swirl Concentrator/Regulator proved to be an efficient device for removing gross "first-flush" related solids from combined sewage. The design of the Swirl Concentrator at Lancaster was determined through laboratory and prototype experimentation to remove (treatment and not by flow-splitting) 90% settleable solids (artificial media meant to replicate combined sewage solids) at a design flow of 40 cfs (1126 l/s). Actual suspended solids treatment efficiencies monitored in fall, 1980 through summer, 1981 exceeded 60% for influent discharges exceeding 20 cfs (563 l/s). Typically "first-flush" occured at the onset of storm events when the flows rapidly peaked. Treatment rates then drastically reduced for later portions of events. Most of the suspended solids were inorganic settleable grit in nature. Persistent influent flow meter malfunctioning precluded accurate estimates of flow-weighted efficiency rates.

2. Settling column tests performed on the influent during storm events indicated suspended solids particle distributions having significantly less larger particles (settling velocities greater than 1 cm/sec or 0.0328 ft/sec) than artificial media used to develop the design. These apparent differences may have been attributable to settling column sample collection techniques. (See conclusion 13).

3. Swirl Concentrator efficiency conclusions reached above were determined using data obtained by automatic discrete sampling techniques. Swirl Concentrator efficiencies determined using differences in measured influent and clear overflow solids particles vs settling velocity distributions were much lower. These apparent differences may have also been attributable to settling column sample collection techniques. (see also conclusion 13).

4. Swirl Concentrator COD treatment performance was noted for several storms to be comparable to suspended solids removals. Swirl Concentrator efficiency rates for volatile suspended

solids, settleable solids and volatile settleable solids were comparable to efficiency rates noted for suspended solids.

5. Swirl Concentrator efficiency rates seemed to deteriorate with flows below design flow. Much lower efficiencies (5%-20%) were typically noted near the end of the sampling events when both the influent flow and solids concentrations were the lowest. Influent flow meters typically malfunction at the start of the event when flows were low and "first-flush" concentrations high.

6. Evaluation results for the Swirl Degritter and Disco-Strainer are inconclusive. Both units rarely functioned correctly due to facility design problems.

7. The Hydro-Brake used to regulate the flow from the Swirl Concentrator foul sewer to the Swirl Degritter during wet weather operation appeared to function correctly and did not clog (soda tin cans which has passed through the Hydro-Brake were frequently noted floating in the Swirl Degritter).

### West Roxbury

8. The Swirl Concentrator and Helical Bend Regulator provided treatment of stormwater related suspended solids. Treatment efficiencies ranged from 5% to 40% and were not flow related. The Swirl Concentrator had been sized to provide 80% removal of settleable solids (artificial media) at a design flow of 6 cfs (170 l/s). The Helical Bend Regulator had been sized to provide 90% removal.

9. Settling column tests performed on the influent to the facility indicated stormwater suspended solids particle distributions having significantly less larger particles (settling velocities less than 1 cm/sec or 0.0328 ft/sec) than artificial media used to develop the design for treatment combined sewage solids. As with Lancaster (but to a lessor extent), these apparent differences may have been attributable to settling column sample collection techniques (same manual sampling procedure used in West Roxbury as in Lancaster see conclusions 13).

10. Swirl Concentrator efficiencies noted in conclusion 8 were determined using data obtained by discrete sampling techniques. Comparable suspended solids efficiency levels were determined using differences in measured Swirl influent and clear solids particles vs settling velocity distributions. The actual

efficiency noted from settleability analyses for several events compared favorably with estimates computed using measured data with theoretical performance formalisms developed in the APWA work (4).

## B. Instrumentation/Sampling Techniques

### Lancaster

11. Special Cross-Sectional samplers capable of taking complete vertical "slices" of fluid over an entire pipe cross section in an automatic discrete mode were developed, tested and installed in Lancaster in Spring, 1981 by EDP Technologies. These devices were placed on the 36 in. (.91 m) influent conduit to the Swirl Concentrator and on the 12 in. (30.5 cm) line to the Swirl Degritter. These devices were installed during the evaluation program to obtain representative solids samples of discharges to the Swirl Concentrator and the Swirl Degritter. During four storm events suspended solids concentrations of the Swirl Concentrator influent were determined on samples obtained by the new Cross-Sectional sampler and on samples simultaneously collected by a Manning model 6000 sequential sampler. An analysis of the data indicated that suspended solids of samples collected by the new sampler were 6 to 7 times more concentrated than samples collected (at the same instant) by Manning sampler during the first 10 minutes of the storm events peak of "first-flush" passage. Concentration factors reduced to 2 to 4 times for samples collected mid-event and then down to 1.5 to 2.0 for end - of-event samples.

12. The set of Swirl Concentrator influent suspended solids multiplicative factors cited in conclusion 11 were used to reassess seemingly poor efficiency performance of an event monitored in fall, 1980 (before special Cross-Sectional samplers were installed) and an event monitored in 1978 during the initial evaluation period. Both events showed good solids removal efficiency using the influent multiplicative factors. It had been concluded (prior to EDP's involvement) that the Swirl Concentrator had been providing negligible to negative solids treatment efficiency.

13. Large volume Swirl Concentrator influent samples taken manually for settleability analyses typically contained suspended solids concentrations much lower than concentrations of samples taken using the Cross-Sectional and Manning) samplers during comparable time periods. It appeared that much of the heavier grit-like material was missed by the hand sampling manual operation which precluded adequate representation of the bed load material.

# CHAPTER 3

## RECOMMENDATIONS

Recommendations derived from this investigation are presented in two major categories, including unit operation, design modifications and instrumentation sampling methodology recommendations.

### A. Design

#### Lancaster

1. The diversion chamber at Lancaster should be revamped to minimize dry weather debris accumulations. The bar screens should be eliminated or placed after the Swirl Concentrator. The diversion floor chamber should be cambered to prevent shoaling. The relative directions of the influent/overflow lines to the chamber should be reversed. The influent flow comes in one side of the chamber and exists to the Swirl Concentrator after traversing the width of the chamber and completing two 90 degrees flow changes. The bypass conduit controlled by the sluice gate operation is on a direct line with the influent to the chamber.

2. A bypass to the Swirl Concentrator should be constructed for diverting dry weather and normal weather and normal wet weather flow around the unit.

3. The concrete walls in the Swirl Concentrator chamber should be trowel-finished or epoxy-coated as to minimize material clinging.

4. The bottom floor and primary and secondary gutters of the Swirl Concentrator should have greater pitch than the present design. There are portions of the secondary gutter where the slope is minimal (and even negative). Debris and large sediment accumulations were visually noted at the upper end of the secondary gutter.

5. The Swirl Concentrator inner assembly should be constructed out of stainless steel in floating lap-seam sections as to minimize thermal warpage/overflow weir-leveling problems. Stainless steel would also eliminate excessive rusting and corrosion. Portions of the inner assembly which was constructed out of "weathering" steel have badly corroded.

6. Permanent washdown piping attached to Swirl Concentrator walls and underside of the weir plate assembly should be eliminated since materials catch on these protrusions. A good

hose washdown system with sufficient length to permit washdown of underside of weir plate would be adequate. (accumulations would be minimized if recommendations 4 and 5 were instituted).

7. The Swirl Concentrator foul underflow should have its flow-limiting device, that is, the Hydro-Brake placed within the Concentrator floor slab and not downstream after a stretch of pipe. Both in Lancaster and in West Roxbury, Hydro-Brakes are located on foul sewer lines away from treatment units. Sediment accumulations constantly occurred within these segments and were a problem in West Roxbury.

8. The activation level within the Swirl Concentrator tank that is presently used to switch the dry weather flow pattern to wet weather operating conditions should be lowered below 18 in. (45.8 cm). Flows as high as 8 cfs (226.4 l/s), that is, part of the "first-flush" can be discharged without Swirl treatment under present setup. Lowering of this level can only be accomplished after the Swirl Degritter operating characteristics have been enhanced.

9. The Swirl Degritter requires major modification to enhance its operation. Severe solids "bridging" constantly occurred during the evaluation program which clogged the unit and precluded an adequate evaluation of the Swirl Concentrator/Swirl Degritter configuration. The major deficiency is the tightness of the apex cone on the bottom of the Degritter. Either the bottom portion of the Degritter cone (solids drawoff point) should be cutoff and/or the slope of cone should be lessened to alleviate the severe "bridging"/clogging problem. Epoxy coating the interior of the Swirl Degritter or fabricating the unit out of stainless steel would have lessened the "bridging" problem. The bottom cone of the Swirl Degritter should also be out-fitted with a pumped counter-current flush/withdrawal system to permit a reasonable and sanitary unclogging procedures.The present design limits unclogging to manual "crow-bar" operation with a single tap for flushwater/drain. Unclogging the Degritter usually results in spillage of Degritter solids on the basement floor of the control building.

10. The screw-conveyor/link belt system for lifting grit from the Swirl Degritter up from the basement floor to a dumpster outside the control building needs splash-plates to avoid spillage during operation. The first segment of this system from the Swirl Degritter is a screw conveyor which should be replaced with a link-belt conveyor. A screw conveyor will tend to compress compactable material in a reverse direction from the forward flow. This problem may have aggravated the solids "bridging" problem in the Swirl Degritter chamber.

11. The telescoping washdown boom located on the Swirl Degritter screw conveyor was meant to wash organics from the grit. Organics would flow back into the Degritter and overflow to the WWTP. This system has never functioned since its operation was dependent upon solids not "bridging" within the Degritter. A simpler method for achieving the same grit/organic separation would involve permitting variable flow into the Degritter and adjusting the overflow throughput hydraulic rate such that only the organics and floatables would pass over the clearwater weir (supernate to WWTP) and grit would settle and be removed. The original design permitted this possibility since a 12 in. (30.5 cm) pinch-valve was originally used to regulate flow. It was replaced with the fixed discharge Hydro-Brake because the pinch-valve frequently malfunctioned and clogged. A much smaller sized pinch-valve would have permitted both a larger throat opening (would not have clogged) and variable flow adjustment.

### West Roxbury

12. The Helical Bend Regulator can be economically constructed by a formed concrete gunite operation on a poured slab foundation.

13. Small diameter Swirl concentrators, that is, less than 12 ft (3.65 m) in diameter should be fabricated of carbon steel with interior epoxy-coated or fabricated using stainless steel. The Swirl Concentrator at West Roxbury was constructed of steel and the interior was epoxy-coated. No washdown system was included and there was no problem encountered due to clinging material.

## B. Instrumentation/Sampling Methodology

14. The Cross-Sectional sampler is recommended for use in any application where careful sampling is desired of a randomly varying heterogenous waste stream of unknown bedload, suspended load and wash load fractions. The rectangular intake slit in the present slider configuration allows a uniform sampling (and integration) over the entire flow depth. An inverted trapezoidal shape would probably allow a more accurate mass representation of different fractions probably present.

15. Large volume samples (30 gal - 113.4 l) samples taken for settling column settleability analysis should be taken by a modified version of the Cross-Sectional samplers used in Lancaster. These devices delivered 1-l samples and could be operated as frequently as one cycle (1-l) per minute. Collection of the required 30 gal over a 10-20 minute period would be impossible using the present configuration. The slit opening could be varied and a different type of carousel used to handling larger volumes.

16. Because of the flow monitoring problems in Lancaster, it was impossible to ascertain how the Swirl Concentrator solids removal efficiency varied with flow rate, particularly during "first-flush" period when significant removals were noted. It would therefore be desireable to assess full-scale Swirl Concentrator performance under sustained and even flow rates over the course of a storm event. The envisioned pump-fed Swirl Concentrator demonstration project upcoming in Saginaw, Michigan will permit this opportunity.

# CHAPTER 4

## Descriptions of Pertinent Treatment Units

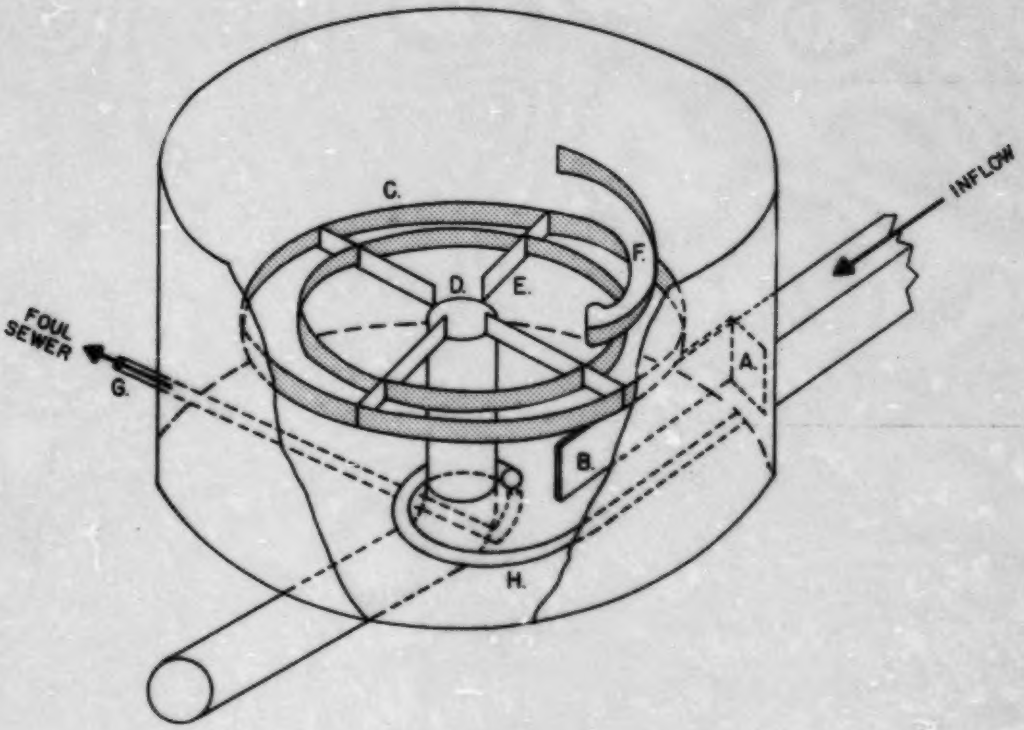
### 4.1 Foreword

Integral parts of the Swirl Regulator/Concentrator and design considerations are presented in Section 4.2. Description of several full-scale swirl installations are also provided in this section. A variation of the Swirl Regulator/Concentrator - the Swirl Degritter is discussed in Section 4.3 along with examples of its practical application. The integral parts of the Helical Bend Regulator are described in Section 4.4. The Discostrainer, an alternative solids separating device which operates by straining, sedimentation and filtration is discussed in Section 4.5. Section 4.6 describes yet another regulator/concentrator - the Teacup Solids Separator. Finally, the most recent innovative solids separating device - the Dynamic Solids Separator is presented in Section 4.7 along with capsulated reviews of four different evaluation efforts. The Dynamic Solids Separator has it's origins with continuing British research to improve the Vortex Separators tested in Bristol, England during the early 60's (2).

### 4.2 Integral Parts of Swirl Regulator/Concentrator Design

As discussed in Chapter 1 the Swirl Regulator/Concentrator is of simple annular-shaped construction and requires no moving parts. An isometric view of the final form of the device was shown in Figure 5. The Swirl provides a dual function, regulating flow by a central circular weir spillway while simultaneously treating combined wastewater by swirl action which imparts solids/liquid separation. Dry weather flows are diverted through a cunette-like channel in the floor of the chamber into the bottom orifice or foul underflow located near the clear water down shaft to the intercepting sewer for subsequent treatment at the municipal plant. During higher flow storm conditions, the low-volume concentrate (3-10% total flow) is diverted via the same bottom orifice leading to the receiving sewer interceptor and the excess, relatively clear, high volume supernatant overflows the central circular weir into a downshaft for storage, treatment or discharge to a waterway.

For an essentially static device to perform efficiently under varying flowrates and suspended solids concentrations, special attention must be given to the various elements within the chamber. (Refer to Figure 5).


C.
F.
INFLOW
D.
E.
FOUL SEWER
G.
A.
B.
H.

A INLET STRUCTURE
B FLOW DEFLECTOR
C SCUM RING
D OVERFLOW WEIR AND HORIZONTAL WEIR PLATE
E SPOILERS
F FLOATABLES TRAP
G FOUL SEWER OUTLET
H FLOOR GUTTERS

Figure 5. Isometric view of Swirl Regulator/Concentrator.

The Inlet Ramp and Transition Section should introduce the incoming flow at the bottom of the chamber and allow solids to enter at the lowest position possible. The inflow should not be turbulent to prevent solids from being carried directly to the overflow weir along with the water and the floor of the ramp should be V-shape to allow for self cleaning during periods of low flow.

The Flow Deflector is a vertical free-standing wall that is an extension of the internal wall of the inlet ramp. It directs the flow around the chamber, setting up the swirl or spiral hydraulic patterns, thereby creating a longer particle path and a greater chance for solids separation.

The purpose of the Scum Ring is to prevent floating solids from overflowing. It should be extended a minimum of 6 in. (15 cm) below the level of the overflow weir crest. The Overflow Weir and Weir Plate connects to a Central Downshaft carrying the overflow liquid to discharge. It's underside acts as a storage cap for floating solids that are directed beneath the weir plate through the Floatables Trap. The vertical element of the weir is extended below the weir plate to retain and store floatables. When the liquid level in the chamber decreases after the rainfall, the floatables exit through the foul sewer underflow.

The Spoilers are radial flow-guides that extend from the downshaft to the scum ring and are vertically mounted on the weir plate which break up the turbulent vortex conditions that if allowed to exist, would impede proper function.

The Foul Sewer Outlet or Underflow is strategically located on the floor of the chamber which allows dry weather flow and concentrated stormflow to exit. It is placed at the point of maximum settleable solids concentration and is designed to reduce the clogging problems that often incapacitate conventional regulators.

Primary and Secondary Floor Gutters are designed for peak dry weather flow and are semi-circular in shape to prevent shoaling and solids deposition.

An Emergency Side Overflow Weir Assembly allows the Swirl to be overdriven to better than twice its design flowrate and still maintain effective settleable solids removal efficiencies. This is accomplished by short- circuiting excess flow and maintaining the integrity of the chamber's separation flow patterns.

Flush Ring Assemblies located around the upper portion of the interior wall of the Swirl chamber and beneath the floatables trap allow for easy clean-up operations following a wet weather treatment event.

Evaluations of the Swirl Regulator/Concentrators have been performed in various locations throughout the U.S. Full-scale facilities have been evaluated in Lancaster, PA, W. Roxbury, MA., Syracuse, NY and San Francisco, CA. Swirl Concentrator demonstration project in Saginaw, Michigan is currently (1981) in design phase. A detailed discussion of the Lancaster Facility and its evaluation is presented in Chapters 5,7,9 and 12 of this report. The West Roxbury Facility is described in detail in Chapters 6,8,10 and 13 of this report.

Syracuse, New York

A 12 ft (3.66 m) diameter Swirl Regulator/Concentrator was installed in Syracuse, NY. (8) Design flow to the swirl was based on maximum carrying capacity of a 24 in. (61 cm) diameter combined sewer inlet of 8.9 mgd (.39 $m^3/s$).

The facility was designed for immediate response to an overflow condition. A flowmeter on the 12 in. (0.3 m) foul sewer outlet line measures dry weather flow and the foul concentrate to the interceptor during wetweather flow. The average dry weather flow range is approximately 0.50 to 0.75 mgd (1.3 to 2.0 $m^3/min$).

Since the downstream capacity of the interceptor is 1.3 mgd (3.4 $m^3/min$), maximum foul sewer flow is quickly reached. Flow in excess of 1.3 mgd (3.4 $m^3/min$) discharges over the Swirl's central overflow weir where it is measured by another flowmeter, disinfected and discharged to the receiving stream.

When the overflow subsides, a foul sewer pump activates and lowers the water level in the Swirl chamber to allow free gravity flow in the floor gutter to prevent solids from settling. Scour velocity is maintained between storms. Sampling was performed at the inlet and outfall locations during overflow events.

The coarse floatables/scum removal mechanism worked satisfactorily. During overflows floatables were contained by the scum ring in the outer ring of the chamber and forced into the floatables trap and under the weir plate for wet weather containment. These pollutants were subsequently drawn down and removed to the foul sewer during dry weather. Relatively good suspended solids removal efficiencies were determined over the entire storm flow range of the Syracuse prototype. Tests further verified that the device is capable of functioning efficiently over a wide range (10:1) of CSO rates, and can effectively separate suspended matter at a small fraction of the detention time required for conventional sedimentation or flotation.

The capital cost of the Syracuse prototype was \$160,930 or \$23,670/mgd (\$1040 $m^3$/sec) and \$2,980/acre (\$1210/ha) (ENR=2700). It should be noted that the Syracuse design closely matched full-pipe flood conditions. Design capacity of the Swirl was not realized in that the facility was hydraulically "under-driven" relative to its design. Withstanding this limitation, the cost of the swirl technology which performed effectively at this site was on an order of magnitude, cheaper than conventional technology.

### San Francisco, CA

A 6ft (1.8 m) diameter Swirl Regulator/Concentrator with a design capacity of 1 cfs (28.3 l/s) was tested in San Francisco, CA using pumped raw sewage from the Richmond-Sunset district. (15) Results of the San Francisco analysis found no significant or measurable benefit attributable to the concentrating effect of the Swirl Concentrator when operating on raw sewage. Concentration reduction ranged from 0 - 5%. Mass removal ranged from 1-4% above that attributable to the flow split. It was later determined after the experiments were completed that the primary difference between these results and the U.S. EPA design tests (3,4) for the unit was the use of well-mascerated raw sewage with very little of the expected grit and settleable material. The design parameters for the Swirl Concentrator were developed using a waste that contained far greater grit than found in San Francisco Richmond-Sunset sewage.

The two top curves in Figure 6 "Proposed Grit" and "Proposed Organics" were materials that the APWA working group specified as being desired to remove in the Swirl Regulator/Concentrator (4). The third curve from the top in Figure 6 shows the settling velocities of particles in a six ft (1.8 m) diameter prototype chamber that were represented by the gilsonite used in the 3 ft. (0.9 m) diameter Swirl model. It can be seen here that over most of the range the gilsonite represented finer materials than those proposed. The exception was at the lower end of the organics where 30% were not covered.

The bottom two curves on Figure 6 show the dry weather sanitary sewage that was analysed at Philadelphia for the primary settler tests (16) and at San Francisco (15).

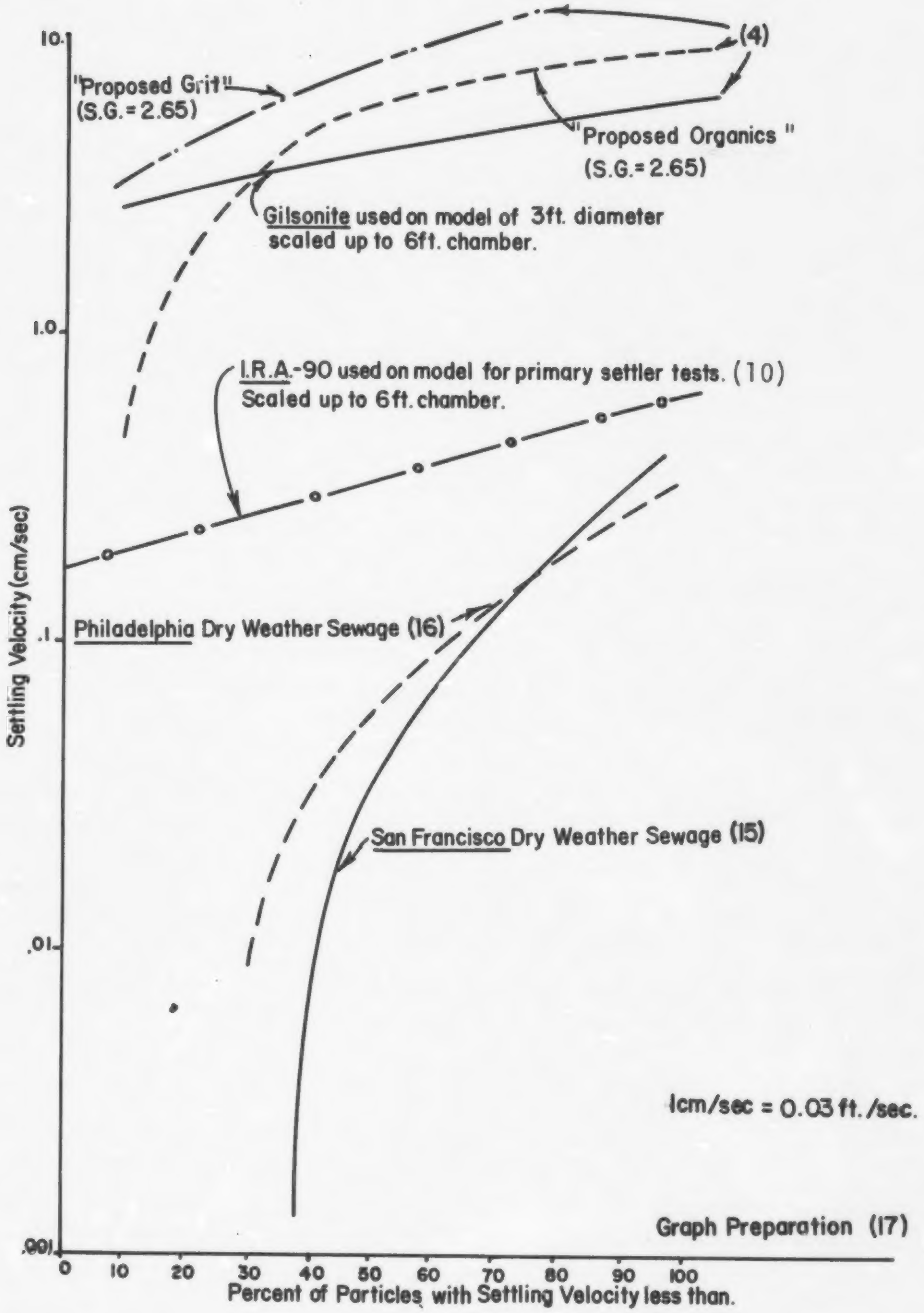


Figure 6. Comparison of sewage settling velocity characteristics used in San Francisco Swirl evaluation with APWA results.

Finally, the middle curve is the artificial media used in the swirl primary settler evaluation tests (10) scaled up to the 6 ft (1.8 m) diameter chamber in San Francisco.

Several conclusions can be made upon inspection of Figure 6. Settling velocities of the San Francisco dry weather sewage falls entirely outside the range of settleable solids settling velocities for which the Swirl Regulator/Concentrator was designed. In fact, settling velocities of the San Francisco sewage were less than those in the reference materials used for the evaluation of the Swirl Primary separator. In sum, the prototype Swirl Regulator/Concentrator should not have been used to treat well-mascerated sewage from the Richmond-Sunset district. No conclusions about the appropriateness of the swirl technology can be drawn from the San Francisco experiments.

## Saginaw,Michigan Swirl Concentrator Demonstration Project

### A. Prior CSO Facility Plan

Abatement of pollution from combined sewer overflows of mixtures of sewage, industrial wastes and stormwater from the City's combined sewer system into the Saginaw River began in 1960. An engineering plan focusing on the combined sewer overflow problem considered utilizing to its maximum the existing system of combined sewers, intercepting sewers, and stormwater pumping stations and proposed the location of storage and treatment facilities at certain locations determined by the hydraulics of the system along the route of the interceptor. (18) The concept of storage and treatment was considered to be the state-of-the-art CSO technology during that time.

The CSO control plan focused on utilizing in-line and off-line storage. In-system storage was available for retention/attenuation of combined sewage through modification of regulators, construction of weirs, restraining of tide gates and other means. In addition, off-line storage at seven locations was recommended to be constructed to retain and treat wet weather flows in excess of the collection and transmission system's hydraulic capacity. Disinfection was recommended to be provided by injection of chlorine into the influent conduits of each storage basin by means of feed pumps and diffusing arrangements. Costs for construction of seven off-line storage/treatment facilities were estimated to be $25 million in 1972, $37 million by 1980 standards.

One of the seven basins of the CSO facility plan has been implemented at the site of the Hancock Street storm and flood water pumping plant at a total cost of $7.1 million. The Hancock

Street facilities serving about 1600 acres (700 ha) of combined sewer area consist of an integrated system of in-line storage controlled by modified regulator stations; a flood protection pumping station; and a storage/treatment basin capable of treating and disinfecting all overflows.

## B. New CSO Facility Plan

In view of these new technological developments and the rising inflationary costs of both the envisioned construction program and the ensuing high degree of operational requirements already experienced in the City of Saginaw applied for, and received a Section 108 grant from the U.S. EPA Great Lakes program, Region V. The grant is entitled, "Demonstration Grant for Control and Treatment of Stormwater from a combined Sewer Overflow in Saginaw," and is divided into the following four phases.

| | |
|---|---|
| Phase 1: | Preliminary Engineering Feasibility Study |
| Phase 2: | Design of CSO Abatement Technology Selected in Phase 1 |
| Phase 3: | Construction and Installation of Equipment |
| Phase 4: | Facility Start-up and Evaluation |

Environmental Design & Planning, Inc. (EDP) completed the Phase 1 study in June, 1980. (19) The study recommended using secondary flow pollution control devices (Swirl Concentrators) in lieu of storage/treatment basins together with extensive utilization of in-line storage and minor structural system modification to increase flow performance of the existing system. A major element of the proposed CSO plan is envisioned as the 108 demonstration facility.

Upon request by City of Saginaw and U.S. EPA, EDP expanded the Phase I Feasibility Study into an alternative CSO Facility Plan for the City. (20) Public hearings were held in January 1981 and the new CSO facility plan was formally adopted and submitted to the Michigan Dept. of Natural Resources. Capital costs for the recommended CSO abatement program were estimated to be 15.7 million dollars.

The costs do not include the presently operating Hancock Street CSO facility.

### Webber Street CSO Facility

One of the major overflow points in the system was selected as the location to construct a major Swirl Concentrator demonstration facility funded by the U.S. EPA 108 Great lakes Program and the City of Saginaw. The facility is located at the

Webber Street Pumping Station and treats overflows from roughly a 1200 acre (523 ha) service area. EDP completed a design development document for the facility in June, 1982 (21). construction plans and specifications will be ready for bidding during early 1982. Construction is envisioned by late spring.

The facility will consist of an in-line control structure capable of generating 220,000 $ft^3$ (6235 $m^3$) temporary storage (wet well) for a 80 cfs (2260 l/s) lift station feeding a 40 ft (12.2 m) feeding a 40 ft (12.2 m) diameter Swirl Concentrator.

The in-line control structure will permit 20 cfs (566 l/s) of combined sewage to constantly pass to a downstream interceptor system. The lift station is instrumentated to activate when the temporary storage is nearing exceedance. Foul sewer underflow from the swirl concentrator will drain by gravity to an interceptor system.

## 4.3 Swirl Degritter

The swirl separation principle was recognized to be useful for other than combined sewer overflow regulation. A natural application of this relatively "flash-type" solids-liquid phase separation is the removal of heavier grit from wastewater flows because such solids are more readily treatable due to their higher settling velocities. It is a new innovation in the separation of heavy inorganic solids from lighter organic materials by selective use of longitudinal flow velocities. It also offers the opportunity to effectively remove grit from either the underflow concentrate (foul sewer discharge) of a Swirl Regulator Concentrator regulator or from normal dry weather and wet weather influents into WWTP.

Hydraulic model tests indicate that the swirl concentrator principle can be utilized to provide the same high degree of performance in settling and removing grit particles as conventional devices.(7) The dynamic action of the Swirl Degritter appears to wash the grit and may result in a minimum of organic materials settled and entrapped with the inorganic grit particles.

The small size, high efficiency, and absence of mechanical equipment in a Swirl grit chamber facility appear to offer advantages over conventional devices. In conjuction with a Swirl Regulator/Concentrator serving as a combined sewer overflow treatment device, it can provide an efficient means of removing the extremely large concentrations of grit which can be anticipated in the foul sewer wastes. The device can be used to provide removal of relatively large quantities of grit and larger organic material which may cause deposition problems for the receiving sewer or WWTP.

The degritting of wastewater is common practice. It is one of the conventional pre-treatment stages in sewage and/or industrial wastes treatment plants. The removal of inorganic grit is provided to prevent excessive wear on subsequent handling operations such as pumping, comminuting and screening of sewage and pumping of sludge. Elimination of inert solids prevents deposition of such material in settling tanks, sludge hoppers, sludge digestion chambers, aeration chambers, pipelines and other locations.

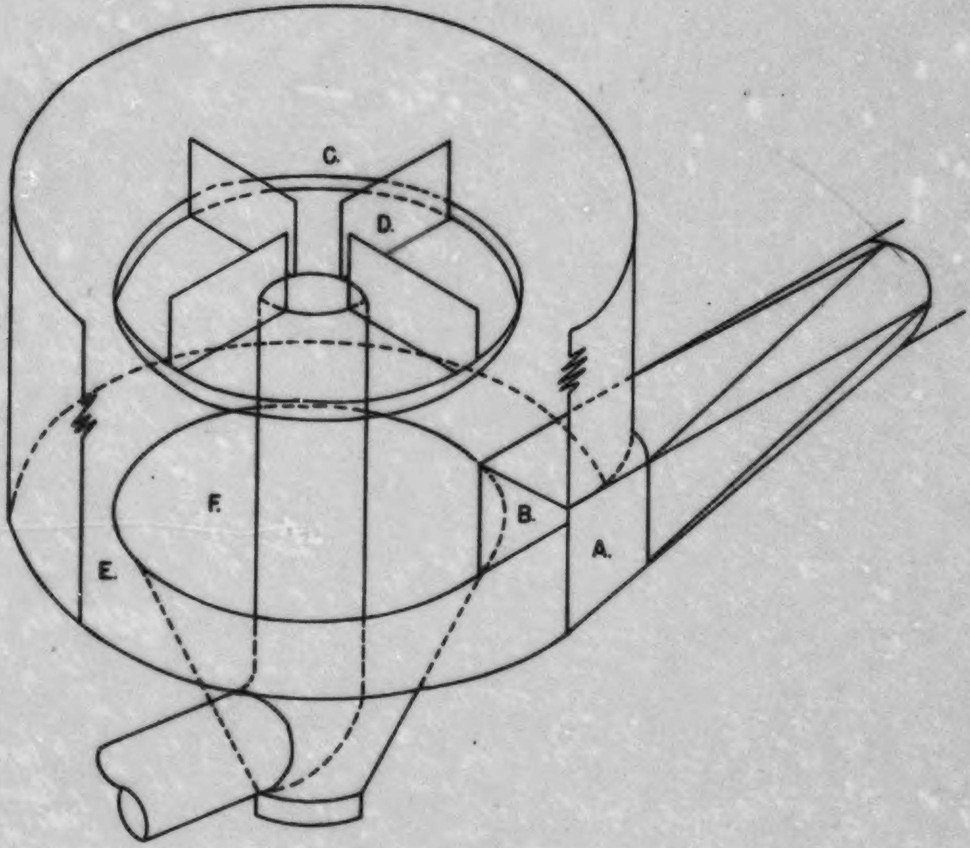
Design of sewers is based on the principle that average sewage solids - organic and inorganic in character - can be held in suspension in a so-called "self-scouring" sewer at flow velocities over 2 ft (0.61 m) per second. Similarly, grit chamber design is based on the principle that heavier grit will settle at velocities of flow of 1 ft (0.3 m) per second, while lighter organics will be held in suspension under these hydraulic conditions until they reach settling chambers where flow velocities are reduced to rates in the general range of 1 ft (0.3 m) per minute more or less. This, then, is the basic criterion for the separation of solids-from-solids in grit units, and the separation of solids-from-liquid in clarification or settling chambers.

The application of the Swirl Concentrator phenomenon to the task of grit removal is dependent on the ability to provide flow velocity conditions and internal hydraulic patterns which will separate heavier, larger solids particles from lighter, smaller materials and to allow the two separated classifications to be collected and removed at separate points.

The general features of the Swirl Degritter are identified in Figure 7, and are described as follows:

(a) Inlet - The inlet dimension is normally designed to allow a inlet velocity of 2 ft (0.61 m) per second. On this basis the inlet diameter becomes the controlling dimension for sizing the unit. A set of curves has been developed to express the relationship between flow, inlet dimension, chamber width and depth. (5) The flow is directed tangentially so that a "long path" pattern, maximizing solid separation in the chamber, may be developed.

(b) Covered Inlet - The Covered Inlet is a square extension of the inlet which is the straight line extension of the interior wall of the inlet extending to its point of tangency. Its location is important, as flow which is completing its first revolution in the chamber strikes, and



A. INLET STRUCTURE
B. DEFLECTOR
C. WEIR AND WEIR PLATE
D. SPOILER
E. FLOOR
F. CONICAL HOPPER

Figure 7. Isometric view of Swirl Concentrator as a grit separator.

is deflected inwards, forming an interior water mass which makes a second revolution in the chamber, thus creating the "long path" flow pattern. Without the deflector, the rotational forces would quickly create a free vortex within the chamber, destroying the solid separations efficiency. The height of the deflector is the height of the inlet port, insuring a head above the elevation of the inlet, a feature which tends to rapidly direct solids down towards the floor.

(c) Overflow Weir and Weir Plate - The diameter of the weir is a function of the diameter of the chamber, and of the inlet dimension. Under normal conditons, the weir diameter is equal to the chamber diameter minus twice the inlet dimension. The depth or vertical distance from the weir to the flat floor, is normally twice the inlet dimension. The height, or rise, of the weir plate is normally 0.25 the inlet diameter. The weir plate connects the overflow weir to a central column, carrying the clear overflow to the interceptor and primary treatment. The horizontal leg of the downshaft should leave the chamber parallel to the inlet.

(d) Spoilers. - Spoilers are radial flow-guides, vertically mounted on the weir plate, extending from the center shaft to the edge of the weir. They are required to break up the rotational flow of the liquid above the weir plate, thus increasing the efficiency of the weir and the downshaft. The height of the spoilers is the same as the inlet diameter. This proportionately large size, as compared to the Swirl Regulator/Concentrator is required because of the possible large variations in diurnal flow which may be anticipated.

(e) Floor - The floor of the unit is level and is in effect a shelf, the width of the inlet.

(f) Central Hopper - The central hopper is used to direct the settling grit particles to a single delivery point where they may be removed to a conveyor for washing and removal from the system. The hopper is at an angle of 60 degrees to the floor. If the angle is less than 45 degrees, particles will build up at the lip. As the angle is increased, the problem decreases to an optimum condition at 60 degrees.

The downshaft elbow must be sufficiently below the floor to prevent formation of eddy currents. This depth appears to be the inet diameter. Structural supports for the elbow and actual pipe connections must be designed to prevent rags from being caught on a protruding bolt head, flange or strut. The downshaft should exit parallel to the inlet to assure a minimum hydraulic interference for settling particles.

Full-scale evaluations of the Swirl Degritter have been accomplished in Denver, Colorado and in Tamsworth, Australia.

## Denver, Colorado

A prototype Swirl Degritter was tested by the Metropolitan Denver Sewage Disposal District No. 1.(7) The unit was designed to duplicate the grit removal device needed to degrit the underflow from the proposed swirl concentrator at Lancaster. Degritting is considered in Lancaster to protect pumps and prevent siltation in the interceptor.

The 6 ft (1.8) diameter device was designed for a flow of 1.5 mgd (656 l/s). It was found that under the physical arrangments in Denver, and testing with domestic sanitary wastewater, that the Swirl Degritter performed at slightly less efficiency than the conventional aerated grit unit which was operating at less than twice the normal flow-through rate. The characteristics of the grit removal from the Swirl Degritter were excellent and particles of .008 in (0.2 mm) were removed.

Analyses of grit removal was accomplished with three Chasick sampling units. Blasting sand was added to provide extremely high concentrations of .008 in. (0.2 mm) particles (lower definition of grit) to duplicate the concentrate from the swirl regulator. It was found that the unit could efficiently remove the small particles at the high concentrations.

## Tamsworth, NSW, Australia

A full scale 22 ft (6.7m) diameter Swirl Degritter was installed as part of the river intake works of the Tamsworth Supply Augmentation project in New South Wales, Australia. (22) The Swirl Degritter was designed for the pretreatment of river water prior to its entrance into the rising main in order to reduce wear and tear on the raw water pumps and also to reduce the solids loading of the rising main and that of the balance tank of the water treatment works. The rate of flow through the system is governed by variable speed pumps which is automatically set by telemetry according to the water level in the balance tank of the water treatment works and the available water in the river. Influent flows vary from 2380 gpm (150 l/s) and 1340 gpm (850 l/s). Grit collected in the bottom of the hopper is removed with a water-jet educter pump through a grit discharge pipeline back into the river. The field evaluation program was initiated with the overall objective of providing information on the behaviour of a full- scale Swirl Degritter, designed and constructed in accordance with the shapes and proportions developed during model studies. Results of the solids removal had been evaluated in terms of three parameters: solids larger than 0.2 mm - the classical size aimed at in grit chambers -, solids larger than 0.088 mm and total settleable solids. In general the tests proved the validity of the laboratory results and at design flow rates 98% removal efficiences were achieved.

## 4.4 Helical Bend

The Helical Bend flow regulator is based on the concept of using the secondary helical motion imparted to fluids at bends when a total angle of approximately 60 degrees is employed. Figure 1, Chapter 1 illustrates the device.

Model studies have confirmed the pattern of solids deposition in the deeper channel portion of the Helical Bend, located along the inner circumference of the bend section, and the ability of dry-weather flows in this restricted deep channel to self-scour the deposited solids into the foul sewer outlet.(11) The basic structural features of significance in the Helical Bend are: the Inlet Section from the entrance sewer to the device; the Transition Section from the inlet to the expanded cross section of the Straight Section ahead of the bend; the overflow side weir and scum board (Treatment Section); and the foul trough, together with the means for controlling the amount of this underflow going to the treatment works.

A more detailed description of the Helical Bend and its evaluation and testing is given in Chapters 6,8,10 and 13 of this report.

## 4.5 Discostrainer

The Discostrainer is a disc-straining device which, because of its design, is able to separate solids by a combination of straining, sedimentation and filtration. The device consists of a series of stainless steel mesh-covered discs in a specifically designed chamber (see Figure 8). Each pair of discs forms a separation unit. The influent is routed into the cavity between pairs of discs and flows outward through the wire mesh leaving the captured solids behind. These trapped solids form a pre-coat material which may aid the filtration effect. A spray system is used to flush the trapped solids from the mesh back into the cavity between the discs. The spray system can utilize filtered water with a built-in recirculating pump or an external water supply. As

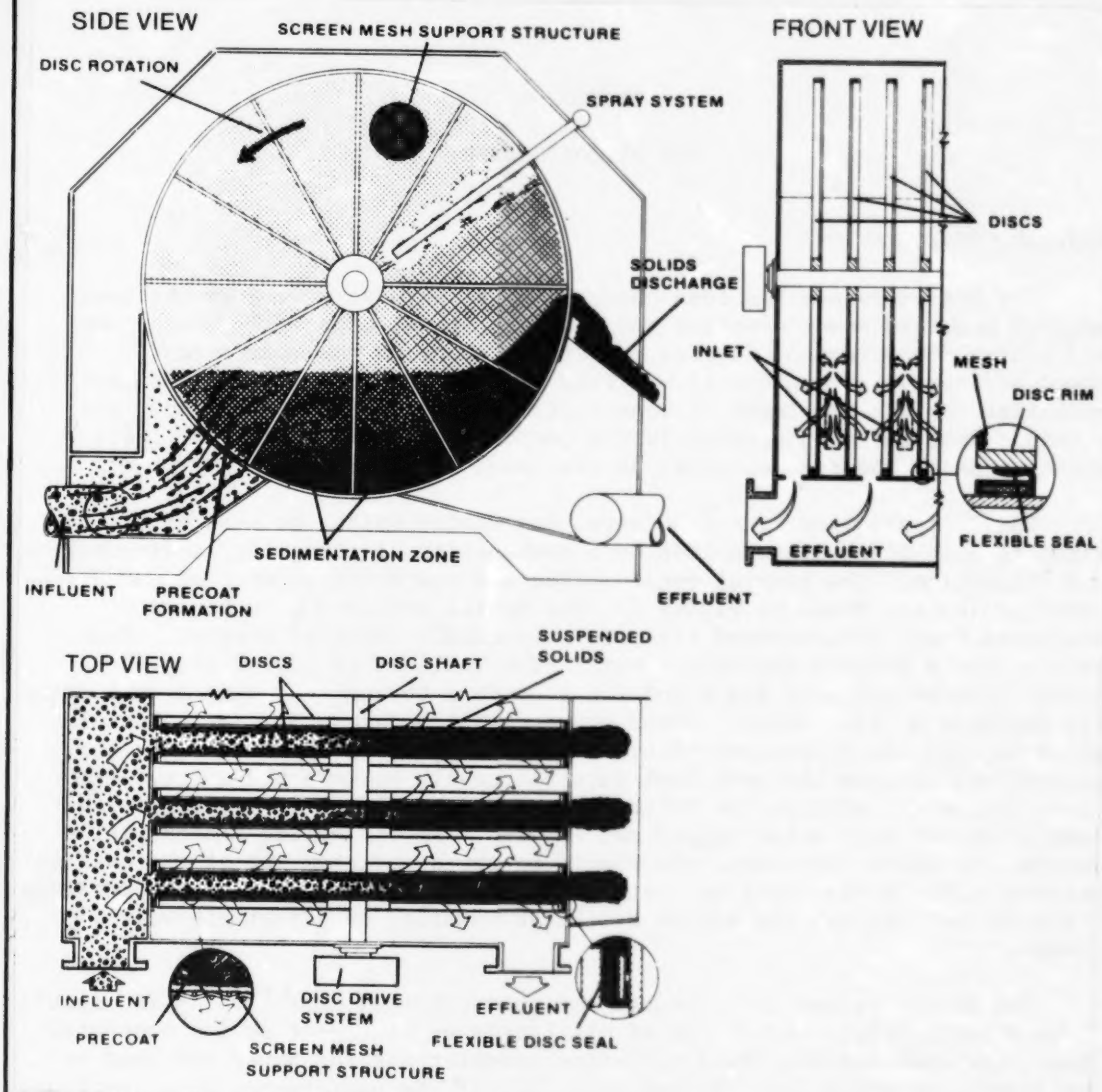

SIDE VIEW
SCREEN MESH SUPPORT STRUCTURE
DISC ROTATION
SPRAY SYSTEM
SOLIDS DISCHARGE
SEDIMENTATION ZONE
INFLUENT
PRECOAT FORMATION
EFFLUENT
FRONT VIEW
DISCS
INLET
MESH
DISC RIM
FLEXIBLE SEAL
EFFLUENT
TOP VIEW
DISCS
DISC SHAFT
SUSPENDED SOLIDS
INFLUENT
PRECOAT
DISC DRIVE SYSTEM
SCREEN MESH SUPPORT STRUCTURE
EFFLUENT
FLEXIBLE DISC SEAL

**Figure 8. Construction and operating features of discostrainer.**

the solids concentration between the discs increases, the slurry in the downstream end of the cavity becomes sufficently thick so that the solids can be swept up by the rotating discs and out through the solids discharge opening, or adjustable weir window.

In an evaluation of the Discostrainer a high speed recirculating jet was used to mix the concentrated slurry and a variable-speed peristaltic pump was used to meter the concentrated slurry into the mixing tube of the influent line. (23)

The Discostrainer was operated with inflow rates of 189, 379, 473 and 568 lpm (50, 100, 125, 150 gpm), fluxes of 126, 253, 315, 379 $lpm/m^2$ (3.1, 6.2, 7.8, 9.3 $gpm/ft^2$), and inflow solids concentrations of 850 to 2270 mg/l. The headloss through the screens was determined by measuring the difference in elevation of the water level in the inlet chamber and the bottom edge of the discs. The influent and effluent samples were taken at the inlet chamber and effluent pipe, respectively. The samples were analyzed for solids concentration using the same procedure as for the tube settler. Flow was established in the Discostrainer by first setting the primary flow of clear water, then starting the disc drive and sprayer pump. The slurry feed system was then turned on to inject the concentrated sediment slurry into the influent line.

Representatives of the local distributor of the unit, Northwestern Power Equipment Company, were notified and observed the initial tests. The initial runs with the Discostrainer were entirely unsuccessful. Immediately after the slurry flow was started the mesh plugged or binded, and the water level in the inlet chamber increased until the water discharged through the overflow outlet. The binding continued as long as the flow was maintained, even after the slurry feed line was turned off. The sprayer system cleared the mesh as the discs rotated past them but the mesh binded again as soon as it re-entered the flow. There was sufficient material trapped between the discs to cause the mesh to bind even when no additional slurry was added. This rapid binding was partially caused by a deficiency in the slurry feed system which caused a surge of high sediment concentration to enter the Discostrainer when the slurry flow was first turned on. The slurry feed system was subsequently modified so the initial solids concentration could be controlled and so long as the inflow concentration was carefully monitored, the screens could be prevented from binding. However, the persistence of this problem illustrates the sensitivity of the square-mesh screen to plugging by granular particles.

## 4.6 Teacup Regulator/Concentrator

The Teacup Regulator/Concentrator resembles a hydrocyclone in external appearance (see Figure 9). A properly designed Teacup unit generates two independent velocity profiles. One is a "forced- vortex" velocity profile which propels dense solids to the periphery of the Teacup due to high angular velocities, and induces a "Teacup" secondary velocity capable of sweeping solids toward the center of the bottom of the Teacup for concentration in the underflow directed to further treatment. "The forced vortex" is induced in the unit by the top tangential introduction of the inflow. The second is a "free vortex" velocity profile which is characterized by a constant angular momentum which can be adjusted to separate less dense organic solids and floatables from the dense inorganic solids forced to the periphery of the unit. Thus, the "free vortex" can be "tuned" to achieve classification of lighter from heavier matter.

A full-scale Teacup solids separation system was put into operation on a carrot washing system at Maggio-Tostado, Inc., Thermal, California.(24) The Teacup solids separator was 4 ft (1.22 m) in diameter and had a design flow of 500 gpm (32 l/s). Throughout this test period, however, the unit operated at 333 gpm (21 l/s). Typically, the Teacup removed in excess of 95% of the total suspended solids. The remaining suspended solids were essentially colloidal in nature. It was also noted that even greater removal levels were achieved when alum was inadvertently added to the waste stream.

During 1978, a Teacup solids separator was evaluated for treating raw domestic wastewater at the Sacramento City Main Wastewater Treatment Facility.(25) The specific objectives were to evaluate removal efficiencies for settleable solids and floatable materials, and to compare the Teacup's performance to that of the City Facility's conventional grit removal process.

The pilot unit was 5 ft (1.52 m) in diameter; had influent, overflow, underflow and floatable flow line diameters of 6 in. (15.2 cm), 10 in. (25.4 cm), 4 in. (10.2 cm), and 2 in. (5.1 cm), respectively; and treated flows up to 900 gpm (57 l/s). Solids removed in the underflow were very similar to grit with an average solids concentration of 62% and average volatile fraction of 13%. Analyses of solids taken from the City's grit chambers showed 92% solids and a volatile fraction of 23%. The City Facility staff reported that 0.5 $ft^3$ (0.14 $m^3$) of grit was removed per Mgal of wastewater treated with minor fluctuations of 0.1 $ft^3$ (0.003 $m^3$) or less. The Teacup removed

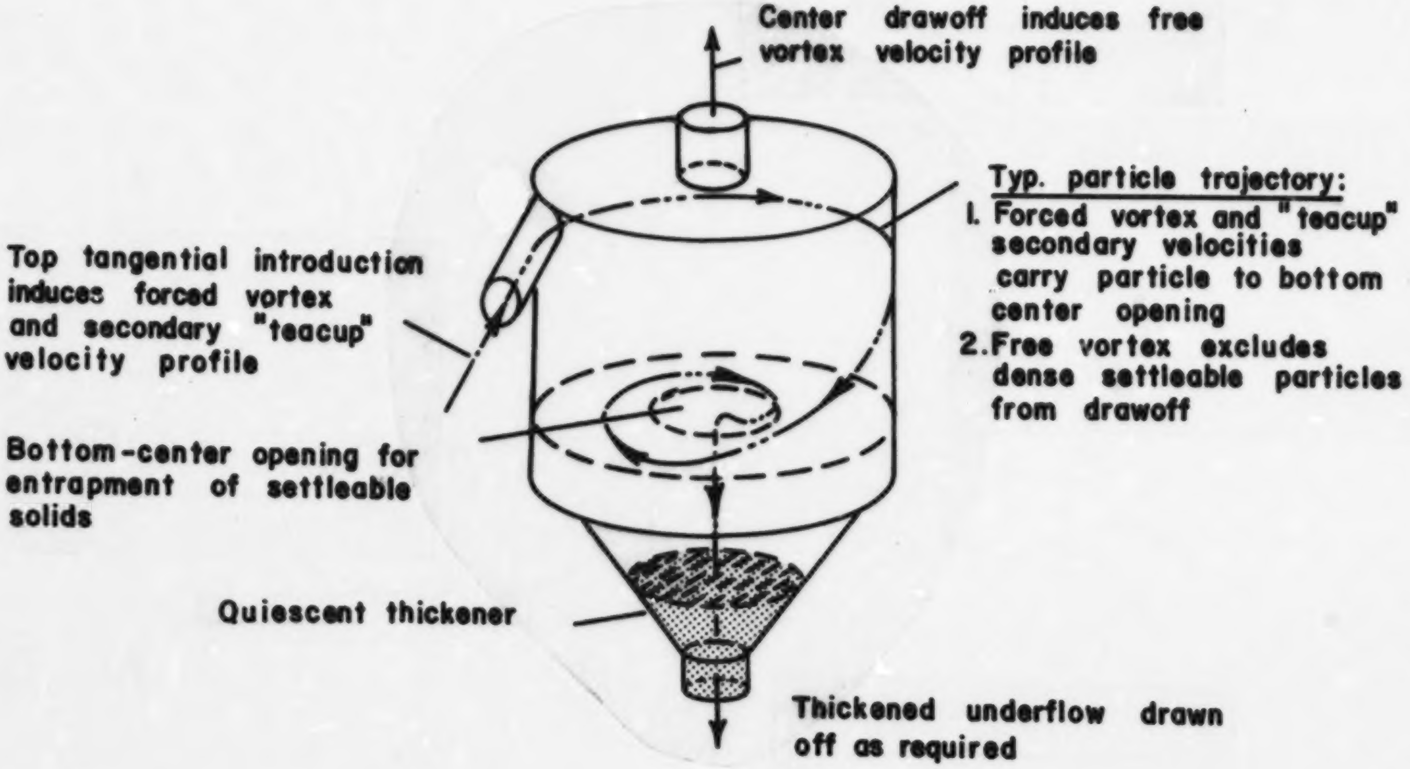

Center drawoff induces free vortex velocity profile
Top tangential introduction induces forced vortex and secondary "teacup" velocity profile
Typ. particle trajectory:
1. Forced vortex and "teacup" secondary velocities carry particle to bottom center opening
2. Free vortex excludes dense settleable particles from drawoff
Bottom-center opening for entrapment of settleable solids
Quiescent thickener
Thickened underflow drawn off as required

Figure 9. Features of the Teacup Solids Separator.

between 3.05 and 3.44 $ft^3$ (0.086 and 0.097 $m^3$) of solids per Mgal treated or from 6 to 7 times as much as removed by the grit chambers.

## 4.7 Dynamic Solids Separator

The Swirl Regulator/Concentrator had its origins from a type of stormwater overflow built in Bristol, England in 1963-64 under the name of Vortex Separators.(2) Considerable research work had been carried out in Bristol in an attempt to improve the stability of the flow pattern in sedimentation tanks for sewage treatment and to develop a compact form of stormwater overflow treatment for a location in a very congested urban area. It was not expected that any significant separation of solids could occur at the high velocities necessary in such compact structures, but both the model tests and later tests of the full sized structures showed that a considerable proportion of the solids in the flow was retained in the foul water outlet.

Several Vortex Separators constructed in Bristol were described in a paper given at a Symposium on Storm Sewage Overflows held at the Institution of Civil Engineers in London in 1967. (2) This paper led to the continuation of the research by the APWA under the aegis of the U.S. Environmental Protection Agency with a specific project at Lancaster, Pa. under consideration. The name of the device was changed to a Swirl Concentrator to avoid the use of the word "Vortex" which is almost universally associated with "free" vortices, a form of vortex which tends to mix rather than separate. The pattern of flow in the Vortex Separator approximates a "forced" vortex and not a "free" vortex.

An 18 ft (5.5 m) Vortex Separator stormwater overflow constructed in Bristol out of brick had a free outlet for the storm sewage overflow. (Photographs of this unit are shown in Figure 10). This design and the design of the Swirl Regulator/Concentrator need a drop of several feet between the incoming sewer and both the foul outlet and the storm outlet. In most existing drainage systems this is not available and the device can only be used where the receiving water course is below the level of the combined sewer or where the pumping is feasible. In completely new drainage systems the necessary head to use Swirl Concentrators as stormwater controls can be "built- in". The really serious problem, however, is in older systems which are overloaded and often in areas where reconstruction is prohibitively expensive.

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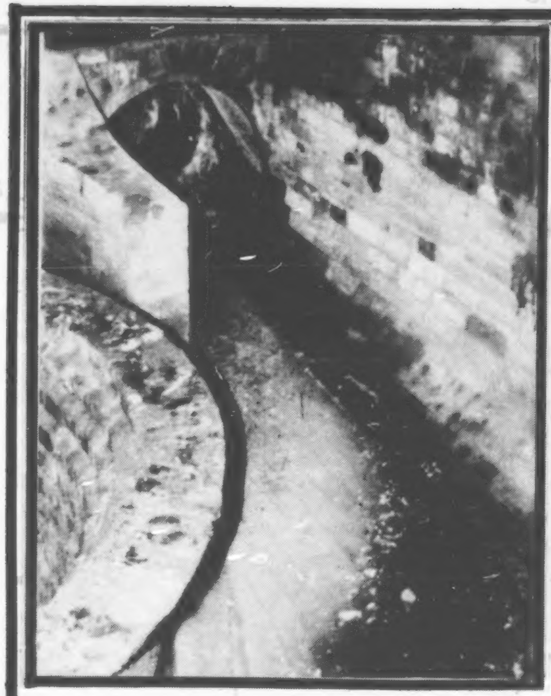
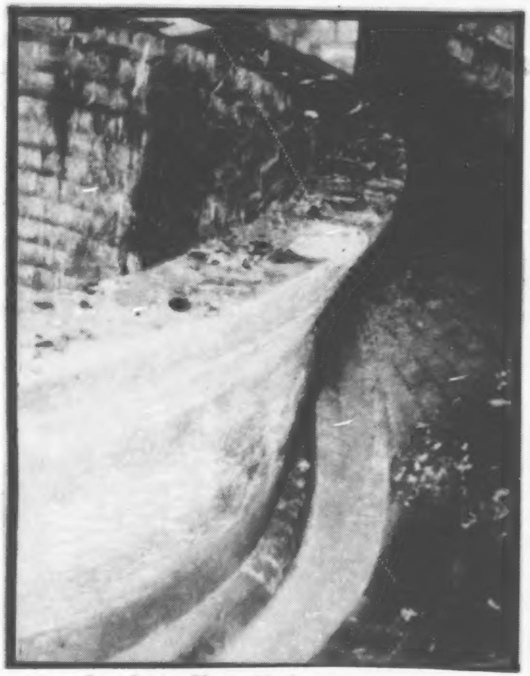


A. Influent section in upper left background



B. Overflow Weir

Figure 10. Photographs of Vortex Separator constructed in Bristol, England.

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In an endeavour to solve this problem, research has continued in England during the same period as the swirl technology evaluations in U.S. A patented device known as the Dynamic Separator has been developed. Figure 11 shows an isometric view of the units with labelled components and a photograph of a 3.3 ft (1m) unit. This device carries out the same function as the Swirl Regulator/Concentrator but with the minimum possible head loss, only the energy needed to rotate the flow being taken from the sewage flow.

The main difference between the Dynamic Separator and the Swirl Regulator/Concentrator is that the decanted flow is taken out of the main chamber upwards through the top of the tank not over a weir and down through the base of the tank. The chamber is kept nearly full even under dry weather flow conditions and is continuously rotating under the influence of the tangential inlet. The velocity of rotation increases as the inlet flow increases.

Vortex Separators have been successfully used for treating a wide variety of different types of waste streams. Capsulated reviews of four pilot plant evaluations not appearing in American literature are reported here. The first effort involved use of the Vortex Separator to remove humus from a trickling filter plant in Blackwell, England in 1966. The second two investigation demonstrates that the Hydro Dynamic Solids Separator is particularly well suited to the needs of industry for the removal of particles from waste process water, thus enabling reuse. The final two investigations document the value of this unit for normal WWTP applications.

Blackwell Pilot Plant

In 1966 Maynard, Froud and Stevens Consulting Engineers (26) proposed a pilot plant treatment system for the grossly overloaded sewage works at Blackwell, England. The works constructed in 1928 consisted of a grit extraction with coarse screening, primary settlement in horizontal flow settlement tanks (originally providing 4 hours detention), percolating filters that were breaking up under the load and ponding, humus settlement in horizontal flow tanks and sludge drying lagoons.

The proposed pilot plant consisted of a Flocar pvc filter with 64 cu yds (.8 $m^3$) capacity measuring 8 ft x 12 ft x 18 ft high (2.4m x 3.7m x 4m). It was raised to discharge 8 ft (2.4 m) above ground level to provide the necessary head to feed to a Vortex Separator. The feed to the Flocor filter was by pump up to the top where a ring pressure main delivered

KEY

A. Inlet pipe
B. Treated Flow Outlet
C. Solids Outlet
D. Cross Section Flow Pattern
E. Inlet Flow Control
F. Treated Flow Outlet
G. Dip-plate to trap Floating Solids to a Floatables Trap
H. Rodding Eye
J. Base Cone
K. Solids Constrained Under Cone
L. Outlet Flow Control Vanes
M. Solids Collection Zone

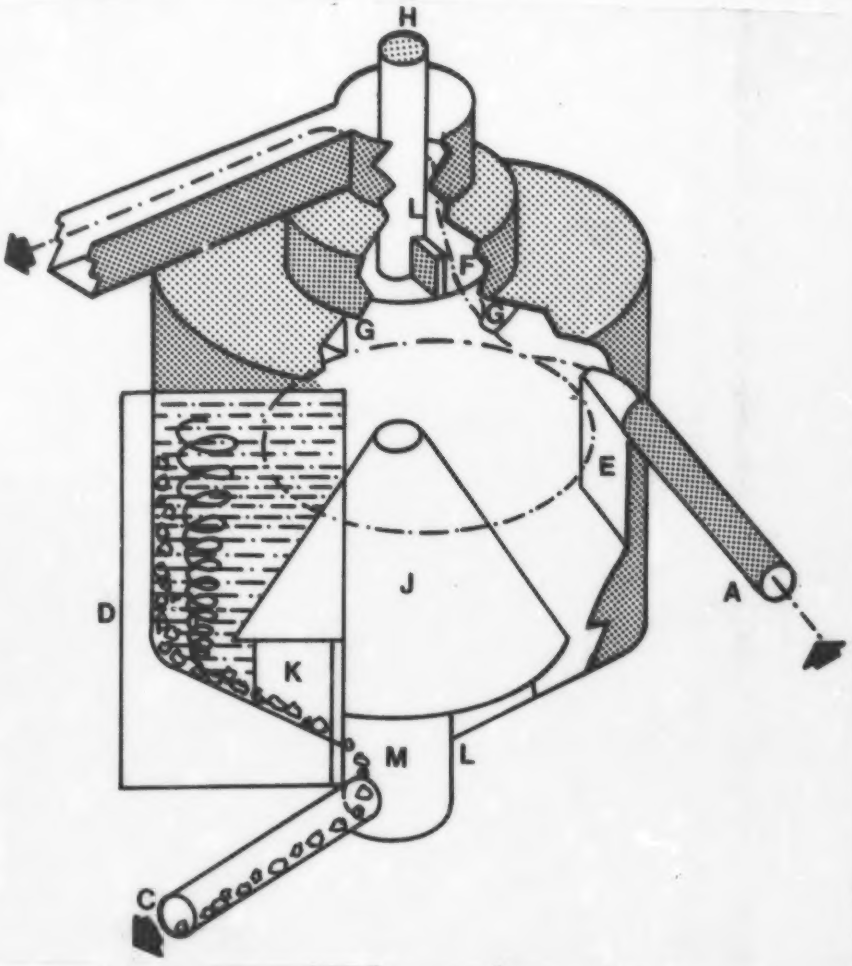

Figure 11 Hydro Dynamic Separator.

to sparges with splasher plates fixed to ensure fairly even distribution over the Flocor. This even distribution was disturbed when any of the sparge pipes blocked with solids in the sewage and the pipes had to be checked and cleared daily. The pump was a Mono pump delivering 125 gpm (472l/m) but a bypass pipe enabled the flow to be varied by bleeding-off some of the flow.

The vortex-type settlement tank was in an 81 in. (2.06 m) diameter tank, 5 ft 6 in. (1.68 m) deep with a central weir. The feed was tangential through an orifice 6 in. (15.2 cm) long under a pressure of from zero to 3 ft (.9 m) head of water. The sludge removed from the central sludge well in the tank passes continuously into an associated sludge holding/thickening tank. The foul flow from the Vortex Separator was maintained by a constant bleed-off from the sludge tank. Figure 12 shows a photograph of the top view of the Vortex Separator and the holding tank.

Up to this point the vortex-type settlement tank had never been tested for use as a sedimentation tank. The vortex tank does not work as a centrifuge, the velocities of flow are not sufficient to give an appreciable centrifuge effect. The principle on which the separation works is where the water is spinning, the lighter particles move faster and reach the center before the heavier particles. The lighter particles leave the heavier particles to fall behind, outwards and down to the bottom of the tank.

The flow pattern in the vortex is not simple. The splitting of the flow into dense and less dense regions causes a break-up of the forced vortex that exists in the outer third of the tank. There is a region of turbulence where a secondary epicyclic vortex motion forms. Two of these vortices form in this region about the central weir with their centers always opposite. These epicyclic vortices are a critical factor for efficient tank performance and when they are eliminated, the tank performance is negligible. They consistently form in the tank and their effect is to trap the denser material and pull it to the bottom of the tank where the flow is towards the center and where the sludge well in the center collects all the solids. The less dense flow, moves round these vortices forming a free spiral vortex at the centre of the tank and passing over the central weir. A photograph of the unit in operation is shown in Figure 13.

The pilot plant was tested by sampling and analyzing the effluents from each unit. The sampling points included raw sewage, flow to Flocor, flow to vortex-type tank and final effluent.

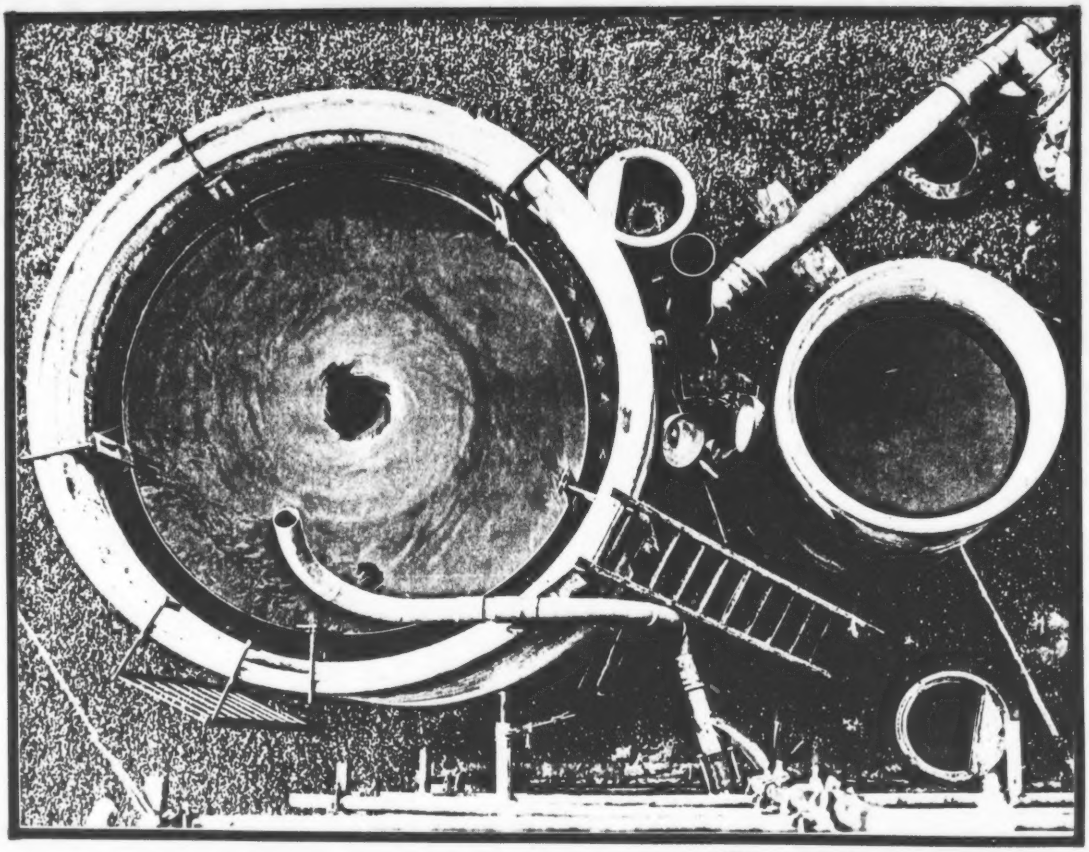

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Figure 12. Photograph showing top view of Vortex Separator and Sludging Holding Tank, Pilot Plant, Blackwell (UK).

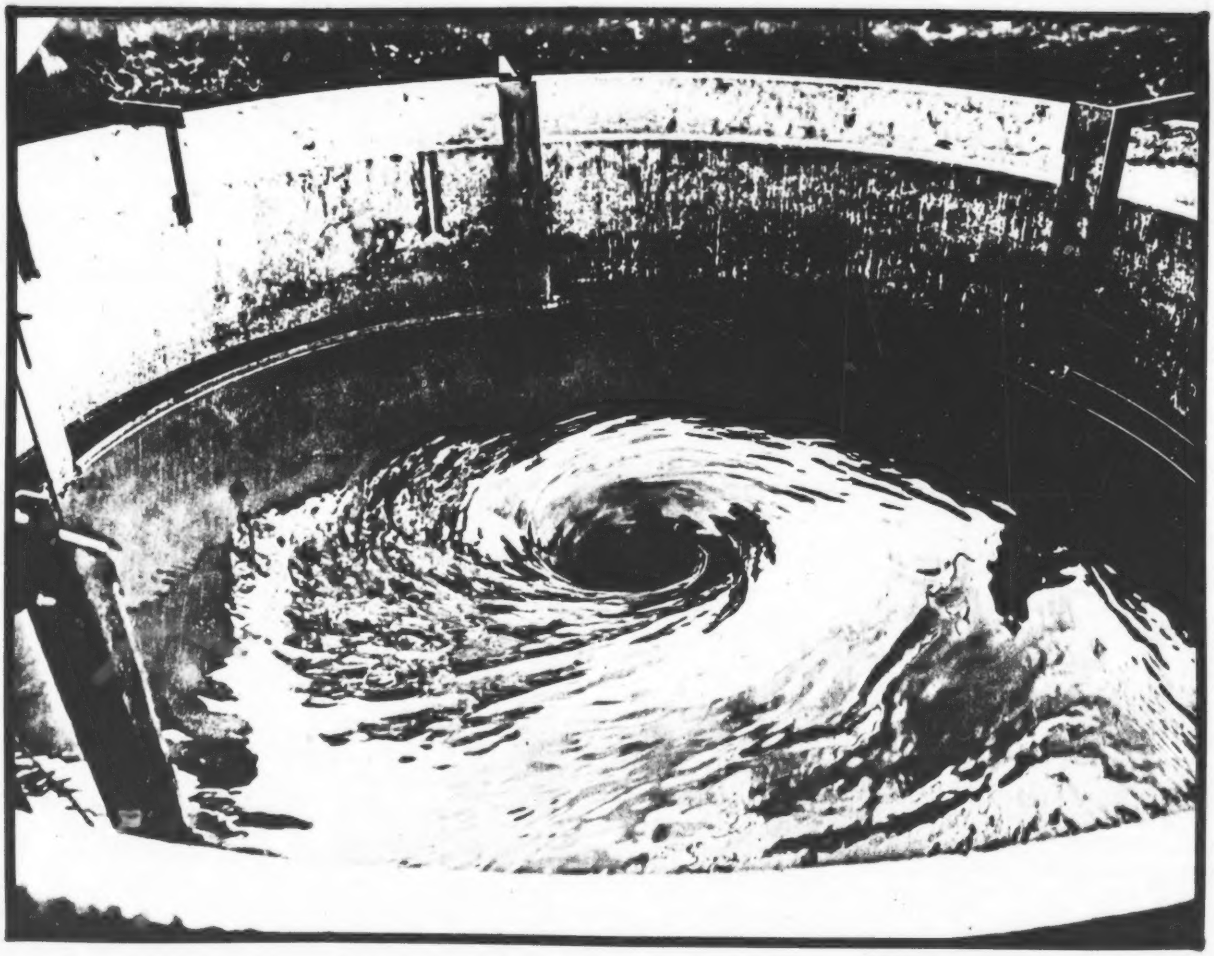

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Figure 13. Photograph of Vortex Separator in operation, Blackwell (UK).

The flow pattern through the treatment plant was as follows. Raw sewage passed through grit channels and then to primary settlement to the dosing chamber. From the dosing chamber the main flow went through percolating filters, humus settlement and discharge to the River Kenn. The pilot plant feed was drawn initially through the Flocor and then on to the vortex-type settling tank and returned either to the dosing chamber or at the inlet to the works or straight to humus settlement. Later modifications enabled the pilot plant to draw raw sewage.

For the evaluation period the pilot plant was set at a flow rate of 98 gpm (370 l/m). The flow from the pilot plant was returned during this period either to the dosing chamber or to the inlet of the works. In either case the returning effluent diluted the incoming sewage and reduced the strength of the flow to the pilot plant. Further operation of the pilot plant included a series of tests in which the vortex-type settling tank was run parallel with a quiescent settlement tank in order to compare their efficiencies. The first test was carried out using crude sewage passing straight to the vortex tank and to one of the detritus tanks adapted for this purpose.

The quiescent tank or adapted detritus tank had a 540 gal (2040 l) capacity. Temporary dams were built to isolate the tank from the normal flow. Its depth was 3.25 ft (.99 m) and length 10.5 ft (3.2 m). The inlet to the tank was over one of the weirs and control of the flow was accomplished by allowing some of the flow to splash outside the tank. Smooth inlet into the tank was then ensured by a series of baffles and temporary dip-plates.

The efficiency of both tanks using raw sewage as feed was low. The average efficiency of the vortex tank was 15.3% and the quiescent tank 12.5% removal of suspended solids. The vortex was 1.22 times as efficient as the quiescent settlement tank.

Further testing involved altering the influent to both tanks to evaluate settling after Flocor treatment. Feed to both tanks averaged 193 mg/l suspended solids. Tests were carried out with detention times of from 50 to 90 minutes in the quiescent tank and 25 minutes in the vortex tank. The results were more consistent, the vortex tank being on average 82% as efficient as the quiescent tank. One explanation of the poor removal results on these runs could be the unusual characteristics of the sewage. Testing of the waste indicated a high level of unsettleable or colloidal particles. The use of a coagulating agent was recommended if used in primary sedimentation prior to inflow into the turbulent vortex chamber.

To arrive at the settleable solids removal efficiency of the vortex and quiescent tanks, an analysis of the sewage after two hours settlement in the laboratory was taken. The results showed that the vortex was 79% as efficient on total suspended solids and 77% as efficient on settleable suspended solids as the quiescent settlement tank. One run of samples was taken to confirm the above results in which the sludge from the separator was sampled as an extra check. The results showed that the vortex tank was 80% as efficient on settleable suspended solids as the quiescent tank.

It was concluded that the normal performance of the vortex tank would provide removal efficiency of 60-80% the effciency of a large quiescent settlement tank, depending on the strength of sewage. This loss of efficiency is in the removal of very small particles that can floculate and be removed in the quiescent settlement tank but cannot form in the vortex tank. A summary comparison is presented in Table 2.

The cost of the vortex-type sedimentation tank is estimated to be approximately 1/10th the cost of corresponding conventional sedimentation tanks. Therefore with the use of the vortex separation the cost of treatment would be only 10% of that of conventional settlement tanks and provide 80% of the solids removal as realized in conventional tanks.

TABLE 2
Comparison of Solids Removal Effectiveness of Vortex Separator with Quiescent Settling Tank

## PERFORMANCE OF VORTEX TANK

(a) Total Solids

| | |
|---|---|
| Raw | 10.92 lb/hour |
| Clear | 7.12 lb/hour |
| Efficiency | 33% |

26% of the total solids went to sludge

(b) Settleable solids

| | |
|---|---|
| Raw | 4.60 lb/hour |
| Clear | 1.72 lb/hour |
| Efficiency | 62.6% |

53% of the settleable solids went as sludge

## PERFORMANCE OF THE QUIESCENT TANK

(a) Total solids

| | |
|---|---|
| Raw | 0.8 lb/hour |
| Clear | 0.47lb/hour |
| Efficiency | 41% |

(b) Settleable Solids

| | |
|---|---|
| Raw | 0.3 lb/hour |
| Raw | 0.08lb/hour |
| Efficiency | 73% |

Detention time in Vortex = 22 minutes
in Quiescent tank 130 minutes

1 kg = 2.2 lb

## (Tubacero) Monterrey, Mexico

Hydro Research de Mexico was commissioned in 1981 to investigate the technical feasibility of treating and reusing wastewater from a major steel pipe manufacturing plant (Tubacero) in Monterrey, Mexico.(23)

Principle water consumers at the plant are the pipe washing section, the high pressure pipe expander and pressure testing machine. The main consumer being the pipe washing section using an average of 40,000 - 53,000 gal (150 to 200 $m^3$) of water per day producing two effluents. The first waste stream is from the scrubbing and first-rinse cycle and is heavily laden with rust particles, mill scale, insoluble oil, detergent and potassium dichromate. The other waste stream is from the final-rinse cycle and is relatively lightly contaminated with the pollutants listed above.

In the analysis of the system the mode of operation consisted of the effluent being taken from a settlement tank and pumped up to the header tank where a constant level was maintained by the overflow pipe. The header tank supplied effluent to a 3.3 ft (1.22 m) diameter. Dynamic Separator through a 4 in. (10.2 cm) and 2 in. (5.1 cm) flexible hose connected to a butterfly flow valve, enabling the adjustment of the flow rate to the device. The treated effluent and underflow were taken off respectively through 4 in. (10.2 cm) and 2 in. (5.1 cm) flexible hose and returned to another settlement tank. After filling the device the system ran for 15 minutes allowing the process to stabilize before sampling. Four different sets of experimental conditions were run with the pilot plant.

Once the color of the effluent from the header tank overflow, the treated effluent and the underflow was visually noted to be consistent for 5 to 10 minutes, samples were taken using Imhoff cones for volumetric analysis of the effluent. Values reported in Table 3-A are for volumes of suspended solids (in ml/l) recorded after half an hour settlement. Values reported in Table 3-B represent the gravimetric analyses of results. Efficiency levels noted in Table 3 are defined as the ratio (%) of foul sewer solids mass rate divided by sum of foul sewer and clear solids mass rates. Applied overflow rates ranged from 1700 to 3500 gal/$ft^2$/day (.80 - 1.60 l/s/$m^2$).

Efficiency adopted in this report for noting performance of the West Roxbury and Lancaster demonstration facilities is defined as the percentage of foul mass divided by influent mass percentage less the percent foul underflow. (See section 11.6) Comparable solids removal efficiencies in Table 3-B would range from 39% to 65%.

## TABLE 3.

### Dynamic Solids Separator Performance Summary
### (Tubercero) Monterrey, Mexico

A. Volumetric Analysis

| Vol. of Solids (ml/l) | | | Applied Rate of Flow (l/s) | | | Flow of Solids (ml/s) | | | Eff. + % |
|---|---|---|---|---|---|---|---|---|---|
| * | ** | *** | * | ** | *** | * | ** | *** | |
| 28 | 2.2 | 550 | 1.87 | 1.79 | 0.08 | 52.4 | 39.0 | 42.9 | 52.0 |
| 10 | 8.5 | 52 | 1.87 | 1.61 | 0.26 | 18.7 | 13.7 | 13.5 | 49.7 |
| 12 | 9.0 | 40 | 1.92 | 1.36 | 0.56 | 23.0 | 12.2 | 22.4 | 64.7 |
| 26 | 2.5 | 175 | 0.94 | 0.80 | 0.14 | 24.4 | 2.0 | 24.5 | 92.0 |

B. Gravimetric Analysis

| Suspended Solids (g/l) | | | Rate of Flow of Solids (g/sec) | | | Efficiency † % | Underflow ++ % |
|---|---|---|---|---|---|---|---|
| * | ** | *** | * | ** | *** | | |
| 0.255 | 0.267 | 4.646 | 0.48 | 0.48 | 0.36 | 43 | 4 |
| 0.200 | 0.197 | 1.210 | 0.37 | 0.32 | 0.31 | 49 | 14 |
| 0.120 | 0.112 | 0.457 | 0.23 | 0.15 | 0.26 | 53 | 29 |
| 0.758 | 0.273 | 6.350 | 0.71 | 0.22 | 0.89 | 80 | 15 |

Key:

* Influent
** Clear
*** Foul Underflow
+ Efficiency = underflow solids flow/(influent & clear solids flow)
++ Ratio of foul flow to applied flow
1 gal/s = 3.78 l/s

### (Agua Industrial) Monterrey, Mexico

The Dynamic Separator was also investigated by Hydro Research de Mexico for the treatment of raw sewage at Aqua Industrial, Monterrey, Mexico on June 23-25, 1981.(24) Sewage is purchased, treated and then mixed with groundwater to serve as process water for a large industrial manufacturing plant. This is a common practice in watershort areas in Mexico. The aforementioned unit tested at Tubercero was set up alongside the open supply channel at the intake works to the industrial plant.

Raw sewage was fed through the Dynamic Separator via the header tank. The rate of flow through the Separator was controlled by either adjusting the level of the header tank before starting the test or by use of the butterfly valve on the Dynamic Separator inlet pipe. The treated effluent and underflow discharge pipes were taken over the measuring tank and kept at a constant height during normal flow, and when actually measuring the rate of flow of effluent or under flow. The proportion of underflow to treated effluent was varied by means of the ball valve on the underflow discharge pipe to determine the efficiency of the Dynamic Separator at varying proportions of underflow to treated effluent.

At each setting samples of raw sewage treated effluent and underflow were taken in Imhoff cones. Volumetric readings for settled solids were taken at intervals of 15 minutes and 30 minutes for each sample. The treated effluent and underflow samples were taken 5 to 10 minutes after the raw sewage sample in an attempt to take into account the time the raw sewage takes to pass through the system and to come out as treated effluent and underflow. The raw sewage sample was taken from the overflow at the header tank. Immediately after sampling, the rates of flow of treated effluent and underflow were measured using a measuring container and a stopwatch. For small flows less than 8.7 gpm (0.55 l/s), a 4 gal (15 l) capacity bucket was used and for flows greater than 8.7 gpm (0.55 l/sec) a 53 gal (200 l) oil drum was used.

Agua Industrial did not possess the required filtering apparatus to permit the accurate measurement of coarse sand and girt. The larger particles which separated rapidly from the rest of the sample in the Imhoff cones were therefore only measured volumetrically and are not included in the gravimetric results for the total suspended solids. Both volumetric and gravimetric solids performance results are presented in Table 4.

Sufficient design data was obtained from the testing program to permit the design and predict the performance of Dynamic Separators up to 4800 gpm (300 l/s) capacity. A 13 ft (4m) diameter Dynamic Separator was recommended to provide the additional primary treatment capacity required by the Aqua Industrial plant. It will provide the equivalent treatment of two 74 ft (22.5m) diameter primary sedimentation tanks. The Dynamic Separator is considered to be far more economic to purchase, install, operate and in its use of the available land than equivalent primary settlement tanks.

TABLE 4

Dynamic Solids Separator Performance Results
(Agua Industrial) Monterrey, Mexico

| Test No. | Rate of Flow l/s | Underflow Ratio | Hydraulic Surface Loading l/s/$m^2$ | Efficiency (%) * | Efficiency (%) ** |
|---|---|---|---|---|---|
| Day 1 | 2.19 | .16 | 1.93 | 20 | 27 |
| Day 1 | 1.87 | .16 | 1.65 | 32 | 41 |
| Day 1 | 1.72 | .32 | 1.52 | 40 | 51 |
| Day 2 | 1.37 | .41 | 1.21 | 55 | 55 |
| Day 2 | 0.92 | .38 | 0.81 | 52 | 88 |
| Day 2 | 1.36 | .20 | 1.21 | 25 | 28 |

* Total solids removal (gravimetric)
** Settleable Solids Removal (Volumetric)

Efficiency (%) = 100 (underflow mass rate)/(underflow + clear mass rate)

Note: 1.0 l/s/$m^2$ = 2113 gal/day/$ft^2$
1 gal/s = 3.78 l/s

## Tilbury Sewage Works

In November/December, 1981 Hydro Research & Development (UK) Ltd. under subcontract to Paterson Candy International (UK) Ltd. investigated the potential application of the Dynamic Separator at the Tilbury Sewage Works for the Anglian Water Authority. The purpose of the investigation was to ascertain whether grit only could be classified or removed from the mixed liquor effluent of a pilot plant deep shaft so that the organic fraction treatment process could continue to aerobic settlement/digestion and ultimately ocean disposal. The mixed liquor contains approximately 5000 mg/l suspended solids, badly foams and contains considerable floatable material. Degasification would normally be necessary prior to application of conventional sedimentation.

A 3.3 ft. ( l m) diameter Dynamic Separator was used for the pilot study. Influent overflow rates of deepshaft effluent to the Dynamic Separator were varied from 450 gal/ft$^2$/day (.22 l/m$^2$/s) up to 4000 gal/ft$^2$/day (1.91 l/m$^2$/s). At an applied hydraulic loading of 450 gal/ft$^2$/day (.22 l/m$^2$/s) and an underflow ratio of 17.6%, the resulting suspended solids concentrations of the overflow and foul sewer were 610 mg/l and 11,730 mg/l respectively, providing an efficiency of 80.5% (foul mass/influent mass) or a net efficiency of 62.9%. At an intermediate hydraulic loading of 1500 gal/ft$^2$/day (.70 l/m$^2$/s) and an underflow ratio of 10.9%, the resulting suspended solids concentrations of the overflow and foul sewer were 300 mg/l and 12,730 mg/l respectively, providing a gross efficiency of 83.9% of a net efficiency of 73%. The desired classification (grit only in foul) occurred at a hydraulic loading of about 1.91 l/m$^2$/s. An unexpected floculation effect (and benefit) occurred at the lower hydraulic loadings. Further investigations are proceeding as of mid-December, 1981.

# CHAPTER 5

## Study Area Description - Lancaster Swirl Facility

### 5.1 Foreword

General area and sewerage system characteristics are presented in section 5.2. Rainfall/runoff and water quality monitoring results obtained for the area are given in section 5.3.

### 5.2 Area and Sewage System Characteristics

The City of Lancaster is located in southeastern Pennsylvania, approximately 50 miles (80.5 kilometers) west of Philadelphia. The City is situated on the western bank of the Conestoga River, which is included in the Susquehanna River Basin.

The City of Lancaster is the urban and socio-economic center of the Lancaster, Pennsylvania Standard Metropolitan Statistical Area (SMSA), which encompasses the area of Lancaster County. In 1970 the City population numbered 57,589 residents, which is 18% of the SMSA's population. The City's area is 7.2 square miles (18.6 square kilometers) with the remainder of Lancaster County being primarily farmland dotted with several smaller rural towns.

The City of Lancaster was founded in the early 1700's and is the oldest inland city in the United States. The first City sewage facilities were installed in the 1860's. During this early period of construction, brick arch sewers were installed to combine and convey both wastewater and stormwater runoff from the central sections of the City to the Conestoga River at several overflow points. This brick sewer construction continued throughout the City until the mid-1930's when most of the major interceptors were completed. However, construction following the turn of the century separated the flows into parallel sanitary and storm sewers.

In 1934, two separate 6 MGD (262 l/s) secondary sewage treatment plants, the North and South Plants, were constructed to treat the sewage flows. Existing CSO outfall locations were connected to pumping stations that carried the flows to the South Treatment Plant. The North Plant received only combined gravity flow. Since most of the City's system is combined sanitary and storm sewerage, the system contained diversion chambers at the pumping stations.

During peak stormwater flows, when the capacity of the pumping stations was exceeded, the diversion chambers would channel excess sewer directly into the Conestoga River. In addition, if the peak hydraulic capacities of the treatment plants were exceeded, excess flow would also be diverted to the river drainage district areas are shown on Figure 14.

The Stevens Avenue drainage district is located in the eastern side of the City (see Figure 14). The district covers 227 acres (55 ha) of which 152 acres (36 ha) are serviced by combined sewers draining to a 60 in. (1.5 m) sewer upstream of the Swirl site. The District boundary, the location of the sewers, and the Swirl site are indicated on Figure 15.

The Stevens Avenue Pumping Station (see Figure 16) is also located on the swirl project site and provides a portion of the total flow to the South Wastewater Treatment Plant. The South Plant presently has a capacity of 12 mgd (524 l/s), serves approximately 69,000 people and has significant industrial input. The older, combined sewers service about half the residential area.

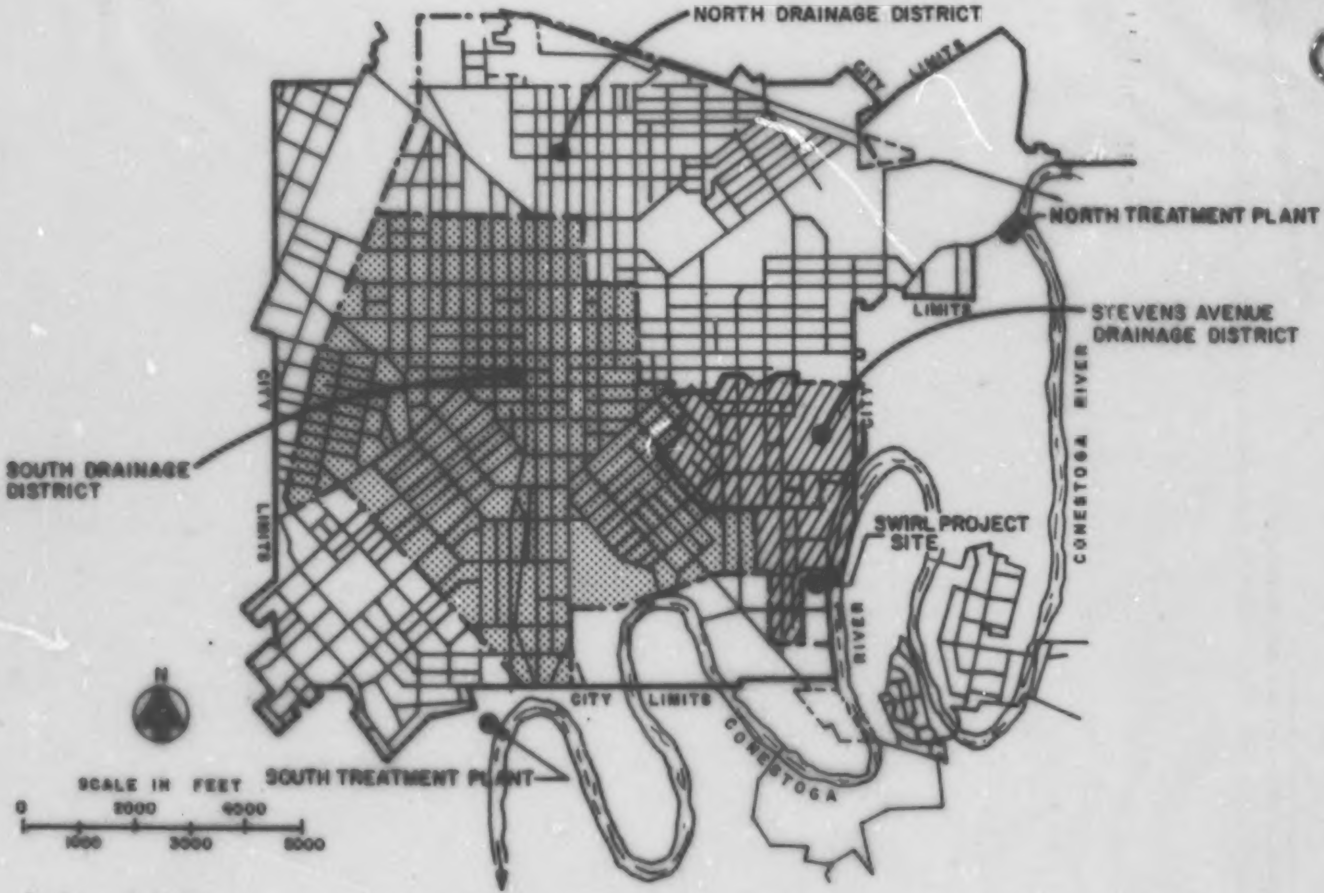
The City of Lancaster and the U.S. EPA elected to utilize the Stevens Avenue District as a demonstration site because of its combined sewers, history of wet weather overflows, compact size and topographic characteristics. In addition, the Stevens Avenue Pumping Station was the only station owned by the City with sufficient land available for the construction of the proposed swirl project.

## 5.3 Monitoring Results

The 250 acre (100 ha) demonstration area is adjacent to the Conestoga River in the southeastern portion of the city, as shown in Figure 14. The developed portion of the area, about 125 acres (50 ha) is residential. The remaining area is parklands or undeveloped fields.

The developed area has an estimated runoff coefficient of 0.59 and would contribute 7,580 $m^3$ (2. Mgal) of runoff to the swirl through the combined sewers, from a 1 in. (2.54 cm) rainfall. The undeveloped half of the drainage area is assumed to contribute runoff directly to the river.

In preparation for construction of the Swirl Regulator/Concentrator facility at the Stevens Avenue outfall to Connestoga Creek, rainfall/runoff and water quality monitoring from the 134 ac (54.2 ha) Stevens Avenue catchment


NORTH DRAINAGE DISTRICT
CITY LIMITS
NORTH TREATMENT PLANT
LIMITS
STEVENS AVENUE DRAINAGE DISTRICT
CITY
CONESTOGA RIVER
SOUTH DRAINAGE DISTRICT
CITY LIMITS
SWIRL PROJECT SITE
RIVER
CITY LIMITS
CONESTOGA
SOUTH TREATMENT PLANT
N
SCALE IN FEET
0
1000
2000
3000
4000
5000

1 ft = 0.3 in

Figure14. Drainage districts within the City of Lancaster, Pennsylvania.

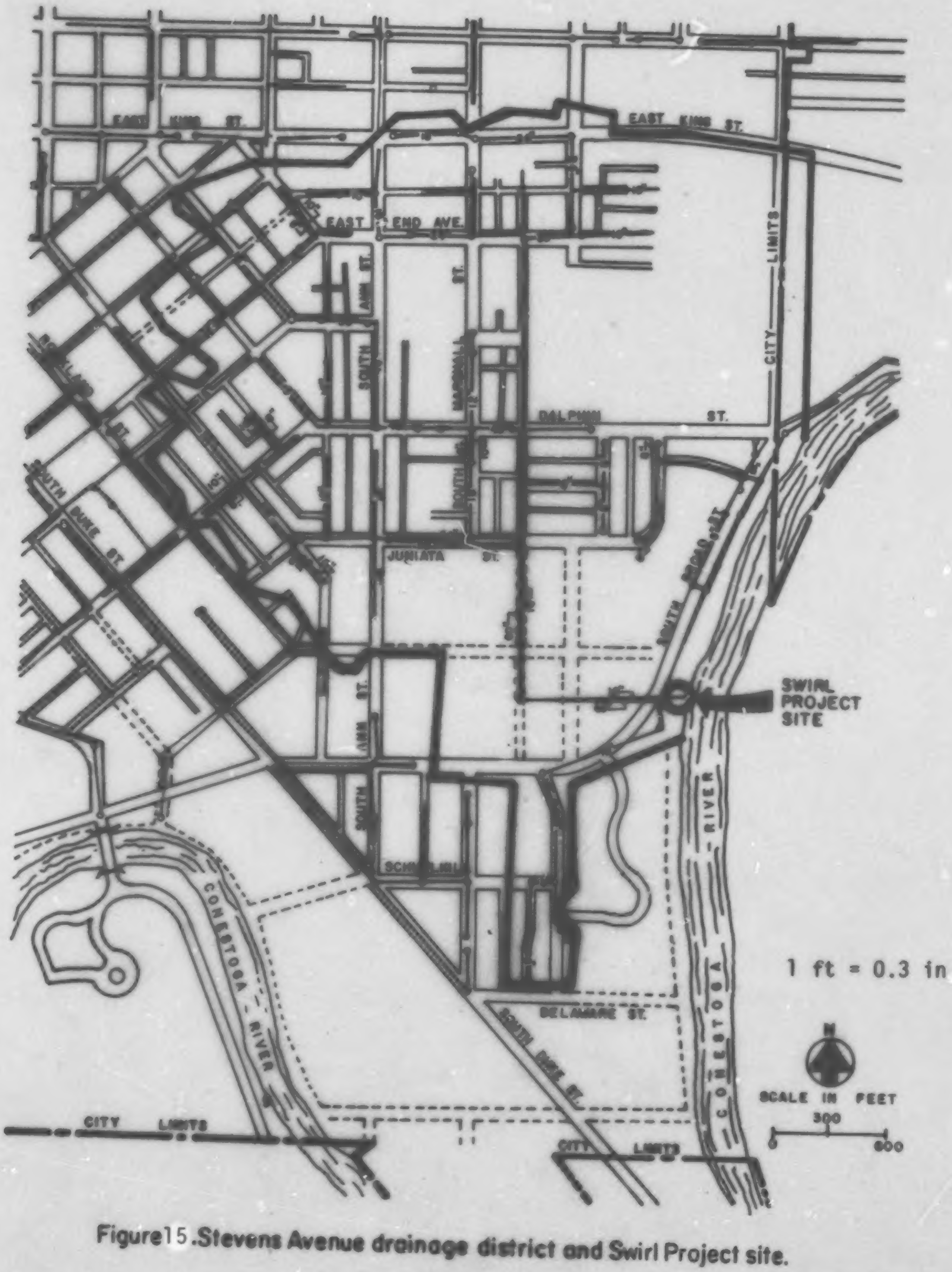

EAST KING ST.
EAST KING ST.
EAST END AVE.
SOUTH ANN ST.
MARSHALL ST.
DAUPHIN ST.
JUNIATA ST.
SOUTH DUKE ST.
SOUTH DUKE ST.
SOUTH BROAD ST.
SOUTH ANN ST.
DELAWARE ST.
CITY LIMITS
CITY LIMITS
CITY LIMITS
SWIRL PROJECT SITE
CONESTOGA RIVER
CONESTOGA RIVER
1 ft = 0.3 in
N
SCALE IN FEET
300
0
600

Figure15.Stevens Avenue drainage district and Swirl Project site.

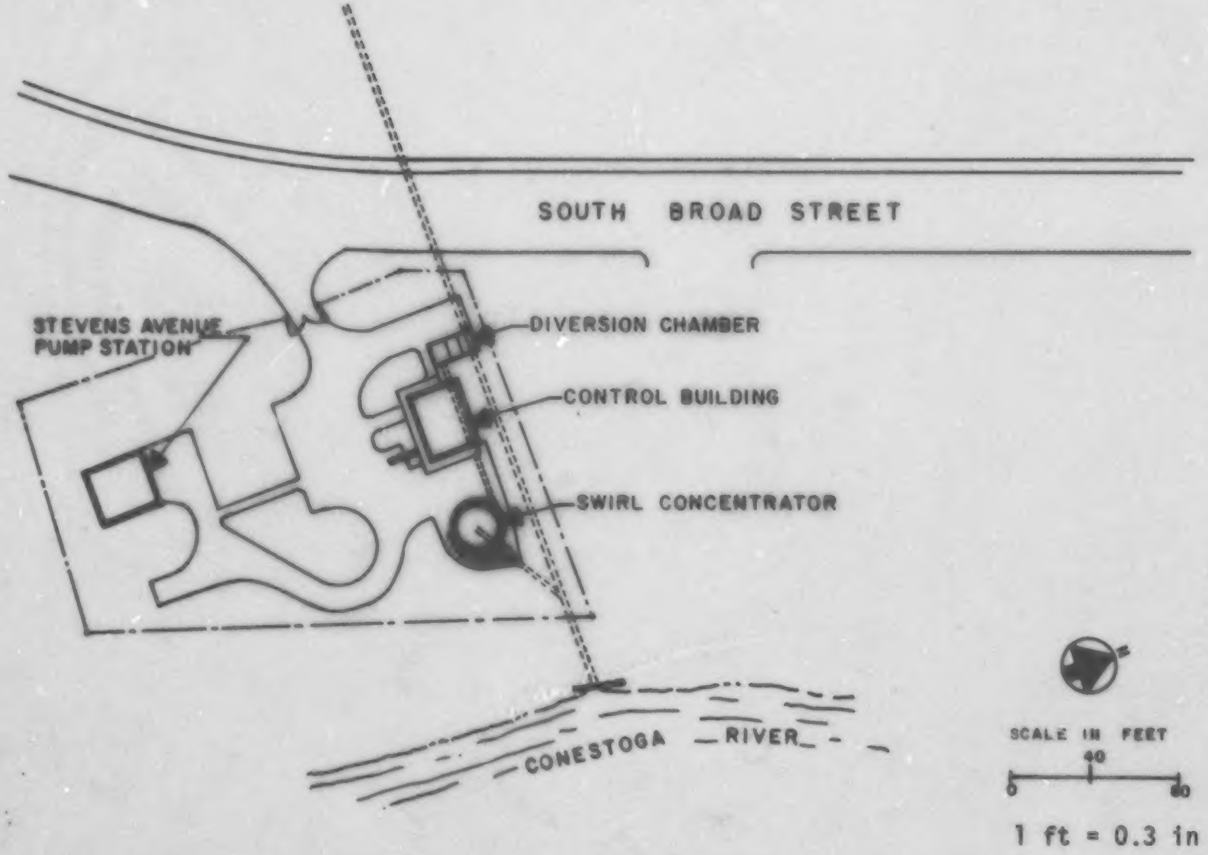

SOUTH BROAD STREET
STEVENS AVENUE PUMP STATION
DIVERSION CHAMBER
CONTROL BUILDING
SWIRL CONCENTRATOR
CONESTOGA RIVER
N
SCALE IN FEET
0
40
80
1 ft = 0.3 in

Figure 16. Lancaster Swirl Project site plan.

was performed in 1973-74 by the City of Lancaster and Meridian Engineering of Philadelphia. (14) Data reduction was performed by the University of Florida.(6)

Rainfall data were obtained using a weighing bucket raingage with five minute sampling intervals. Depth measurements were made in 60 in. (152 cm) RCP sewer by Controlotron Corp 290-1 sonic water level sensor. Continuous strip chart records at depth were converted to flow using Manning equation, (n = 0.013, slope = 0.035).

Supercritical flow at the measuring point eliminated backwater effects. The automatic depth gage recorded values at 18 second intervals and later averaged to provide 1.5 minute weighted averages. Computed flows were highly variable and changed by over 100 cfs (2.8 $m^3$/sec) within minutes owing to the steep "flashy" character of the catchment. Six storms were monitored between September, 1973 through January, 1974.

# CHAPTER 6

# Study Area Description-West Roxbury Swirl Facility

## 6.1 Foreword

The rationale used in selecting a site for the demonstration Swirl/Helical Bend regulator treatment complex is presented in section 6.2. Descriptions of the study area are given in section 6.3. An analysis of long-term rainfall characteristics within the Boston metropolitan area is presented in section 6.4. Utilization of the U.S. EPA Stormwater Management model (SWMM) to estimate a composite runoff factor for the selected area is presented in section 6.5. The runoff factor was used in a further analysis described in chapter 8 in which the design flow for the West Roxbury facility was selected.

## 6.2 Study Area Selection - Background

In 1977 the Swirl Regulator/Concentrator was being examined by U.S. EPA and others as a suitable compact device for removing solids and particulate material from combined sewer overflows. At that time the swirl had yet to be tried for removing pollutants from a separate storm sewered area. Generation of operational experience using the Helical Bend regulator was still in its infancy. Full-scale field demonstration of the Helical Bend regulator had yet to be conducted. The project aim was to determine the effectiveness of a full-scale installation using both devices, side by side, for removing storm sewer related pollution emission loadings.

A design flow of approximately 15 cfs (.43 m/s) with an even split into the two regulators was arbitrally chosen as the envisioned project level on a full-scale basis. The underlying rationale for this choice was the economics of limited research funding and the expected hydrologic yield from approximately 100 acres (43.4 ha) of urbanized land. Runoff from a 100 acre parcel seemed to offer real world potential. The project scale was therefore tempered by both the "reasonableness" of a real-world control situation and available research money.

Another factor influencing site selection was the envisioned mode of treating intermittent stormwater discharges.The hydraulic flow considerations for the regulators at the envisioned site differed from past CSO experience in Lancaster and Syracuse. First, dry weather sewage base flow is not present and the units would not be operating in the CSO mode where treatment begins when downstream pipes cannot hydraulically handle discharge and overflow occurs. In this situation, these devices simply treat all intermittent wet weather flows. The foul sewer connection of both devices to the receiving sanitary sewer could discharge considerable stormwater runoff for low-intensity/short duration storms. This implied that the selection of the design flow range where reasonable treatment efficiencies could be expected for most storm events was crucial since the foul sewer discharge is taken to be 3-5% of design flow.

Another factor influencing site selection was the notion of choosing design flow on the basis of "pollution control" concepts. It seemed at the time that the selection of the particular design discharge should emphasize probabilistic pollution-reduction concepts versus the more conventional notion of size selection on the basis of some reasonable extreme hydrologic/hydraulic event. The cost of most wet weather control facilities designed on the basis of high flow extreme event hydrology is most often much higher than the ensuing costs of control programs aimed at probabilistic pollutant reduction levels. This argument had significant historical prescedent at the time since the general federal viewpoint on the control of stormwater related pollutant loadings was to encourage municipalities to reduce storm sewer emissions by and large, through non-structural "public works" oriented practices. The funding reality at that time (and still is) was that there was no federal funding mechanism to deal with stormwater related pollution. Limited solids reductions in storm sewered loadings, on the order of 30-50% were common section 208 planning recommendations.

The results of a rudimentary simulation analysis indicated that a residential area (it was decided to concentrate on a residential area) of approximately 100 acres (43.4 ha) would be required to meet the criteria previously discussed. Urban sectors in the greater Boston area tend to be densely populated making the location of a physical site difficult. A site of roughly 100 ft x 100 ft (32.8 m x 38.8 m) would be required in an open area (inexpensive construction) somewhere at the end of a separate storm-sewered residential catchment area. To further complicate matters (truly the most difficult aspect) was the requirement for gravity operation especially in the case of the swirl. Since the receptor of the swirl foul sewer effluent would be a sanitary sewer , an elevation difference of roughly 3 to 5 ft (.91 to 1.5 m) below the storm drain (invert to invert) would be required. The sewer line would also have to have sufficient capacity and fluid shear stress to handle and transport solids from the foul sewer effluent. Adequate head would also be required for gravity operation of the clear water overflow.

After reviewing roughly 15 areas in five communities for over a year, EDP finally came upon a site in West Roxbury, Boston that was reasonable and met the aforementioned criteria for the demonstration project.

## 6.3 Study Area Description

Figure 17 shows a map of Greater Boston and the approximate location of the facility. The proposed catchment area lies in West Roxbury, just north of the Dedham line approximately eight miles southwest of downtown Boston. West Roxbury is a section of Boston, and the sewers in question are therefore totally under the jurisdiction of the Boston Water & Sewer Commission (BW&SC).

The land use of the West Roxbury (Boston) study area is depicted in Figure 18 and may be typified as moderate income residential, with mixed commercial occurring primarily along several main road tracts. General housing density in the area is moderate, with lawns and streets in generally good condition. The sewer system in this area is entirely separated (as constructed), with the exception of a few streets. The approximate median age of the housing in the area is 40 years. Drainage from the area discharges primarily into the Upper Charles River through an extensive drainage system. Topography in the area varies from moderately hilly to flat.

## 6.4 Analysis of Long-Term Rainfall Records

Magnetic tapes containing unedited precipitation records were obtained from the National Climatic Center, North Carolina. One tape contained 10 years of hourly rainfall records (1964-1973) for the following gaging locations: Logan Airport and Blue Hills Observatory (see Figure 17). The tape required careful editing to detect missing gaps (less than .8% of the total record). Most often, cumulative estimated end-of-the storm totals were given for missing sequences of hourly records. A temporary data file on disc storage containing edited data, was generated from the magnetic tapes for each station. The data files for the two primary stations contained approximately 1000 wet days each, spanning over the 10 year period.

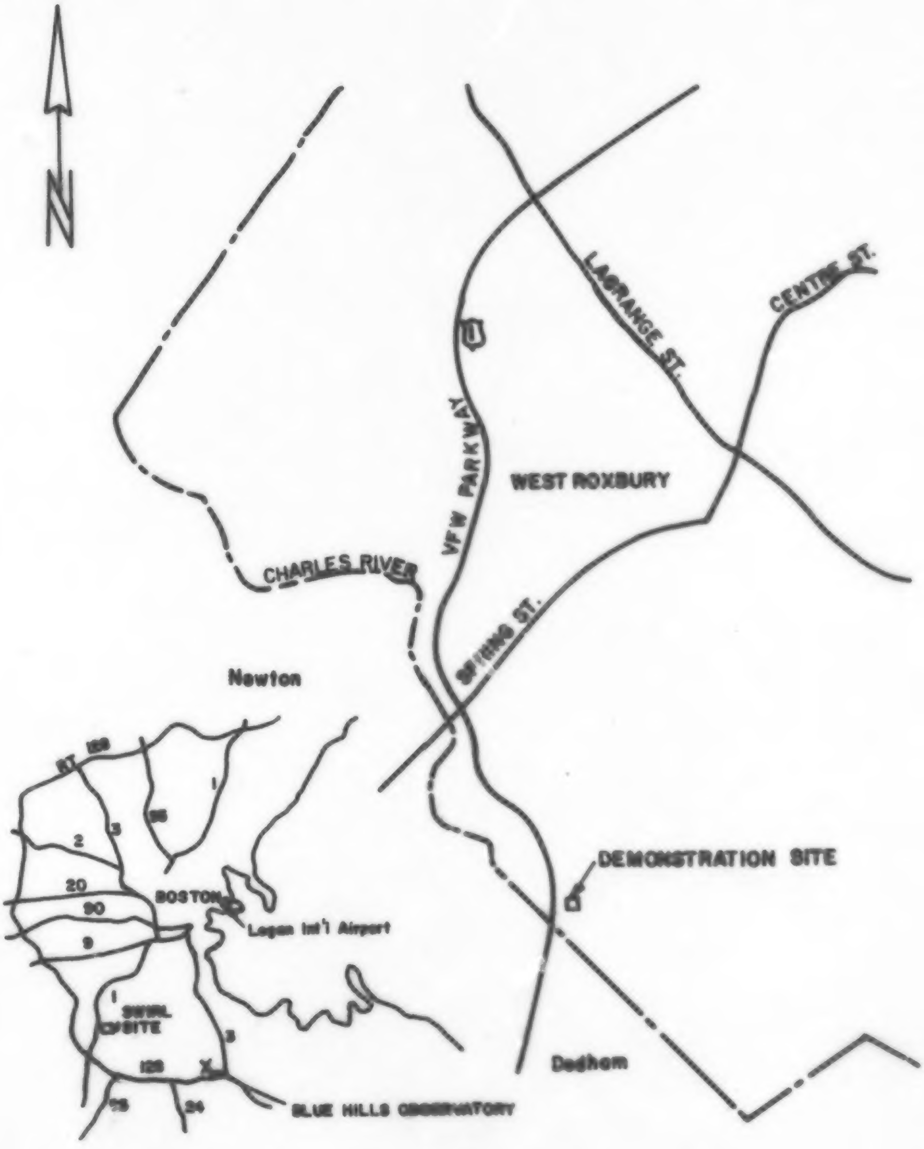

N
LAGRANGE ST.
CENTRE ST.
VFW PARKWAY
WEST ROXBURY
CHARLES RIVER
SPRING ST.
Newton
DEMONSTRATION SITE
Dedham
RT 128
2
3
95
1
20
90
9
BOSTON
Logan Int'l Airport
1
SWIRL SITE
3
128
X
28
24
BLUE HILLS OBSERVATORY

Figure 17. Locational map of West Roxbury Swirl site.

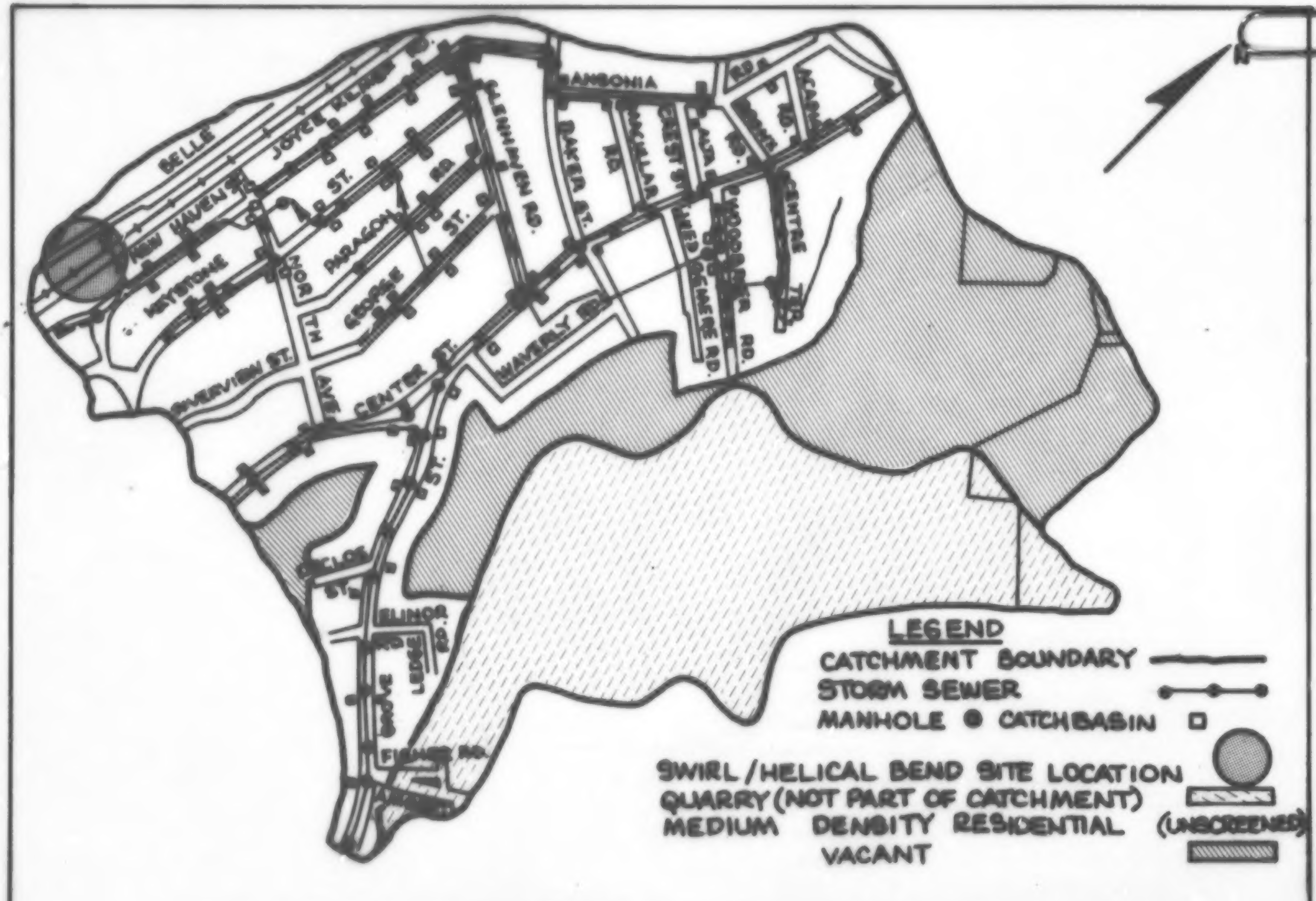

BELLE
JOYCE KILMER RD.
NEW HAVEN ST.
KEYSTONE
ST.
PARAGON RD.
GEORGE ST.
NORTH AVE.
RIVERVIEW ST.
CENTER ST.
GLENHAVEN RD.
BAKER ST.
ANSONIA
MACMILLAN RD.
CREST ST.
ALTA
RD.
CENTRE TER.
WOODBRIER RD.
WAVERLY RD.
RD.
ELINOR RD.
LEDGE RD.
GROVE
FISHER RD.
ST.
LEGEND
CATCHMENT BOUNDARY
STORM SEWER
MANHOLE ● CATCHBASIN ▫
SWIRL/HELICAL BEND SITE LOCATION
QUARRY (NOT PART OF CATCHMENT)
MEDIUM DENSITY RESIDENTIAL (UNSCREENED)
VACANT

Figure 18. Land use map- West Roxbury demonstration project.

The next phase of the computer analysis involved defining discrete events from the continuous edited time series of hourly precipitation records. A sequence of antecedent dry periods and storm events were constructed in the following manner. A storm was defined when the cumulative rainfall exceeded 0.05 in. (1.3 mm) of rain. During the first three hours of rainfall, if the hourly precipitation value was less than 0.03 in (0.8 mm) the precipitation was included in the total rainfall of the event but the periods were not included in the duration of the storm event. A separation in rainfall of a minimum of six hours defined a new storm. It was assumed that storms characterized by a total rainfall of less than 0.05 in (1.3 mm) just wet the system and would cause little, if any, runoff. These periods were considered as part of the antecedent conditions. The same assumption was made when the first three hours of rainfall were less than 0.03 in. (.8 mm).

For every storm event, the following information was computed: a) the year, month and day the storm began; b) the hour of day the storm began; c) the length of the dry period preceding the storm event; d) the total amount of rainfall in the storm event; e) the total duration of the storm event; f) the maximum hourly precipitation in the storm event; and g) the hour of maximum rain within the storm event.

Another set of data files were prepared containing this informational set for the two stations. Statistical computations were then performed on the following six storm event parameters: a) dry days; b) total rainfall of the storm event (in.); c) duration of storm event (hours); d) average intensity of the storm event (in./hour); e) maximum hourly rain in the storm (in./hr); and f) hour of maximum rain in the storm.

Overall statistics are given in Table 5 for antecedent dry days between storm events, total rainfall (in.), duration (hours), average intensity (in./hr), max. hourly intensity (in./hr) and hour when maximum rainfall occurred. Seasonal statistics were also computed but are not presented.

## TABLE 5

## Comparative Analysis of Rainfall Statistics

## Logan Airport vs Blue Hill (B.H.) Observatory
(1964 - 1973)

| | | * | ** | *** | † | †† |
|---|---|---|---|---|---|---|
| A | Logan | 4.5 | 4.1 | 0.9 | 0.25 | 23.1 |
| | B.H. | 4.3 | 3.8 | 0.9 | 0.25 | 26.8 |
| B | Logan | 0.53 | 0.59 | 1.1 | 0.05 | 5.1 |
| | B.H. | 0.59 | 0.71 | 1.2 | 0.05 | 7.7 |
| C | Logan | 8.9 | 8.1 | 0.9 | 1.0 | 48.0 |
| | B.H. | 9.1 | 8.9 | 0.9 | 1.0 | 76.0 |
| D | Logan | 0.07 | 0.07 | 1.0 | 0.008 | 0.87 |
| | B.H. | 0.08 | 0.08 | 1.0 | 0.008 | 1.30 |
| E | Logan | 0.15 | 0.14 | 0.9 | 0.01 | 1.56 |
| | B.H. | 0.15 | 0.14 | 0.9 | 0.01 | 1.52 |
| F | Logan | 4.0 | 4.5 | 1.1 | 1.0 | 39.0 |
| | B.H. | 4.1 | 4.7 | 1.1 | 1.0 | 39.0 |

| | | |
|---|---|---|
| * | Mean | 1 in. = 2.54 cm |
| ** | Standard deviation | |
| *** | Coefficient of Variation | |
| † | Minimum | |
| †† | Maximum | |

Notes:

A - Antecedent dry period - days
B - Total Rainfall per event - in.
C - Duration of storm (hr)
D - Average storm intensity - in./hr.
E - Maximum hourly intensity in./hr.
F - Hour of maximum rainfall intensity

No. events: Blue Hills - 786 storms
Logan Airport - 747 storms

## 6.5 Hydrologic Modeling of Catchment Area

The U.S. EPA Stormwater Management Model (SWMM) was used to calibrate several measured "snap-shot" rainfall/runoff events in the study area. The purpose of this effort was to derive a reasonable overall estimate of the watershed's composite runoff coefficient which was later used in the long term (10 year) simulation analysis described in Chapter 7.

### BASIN SCHEMATIZATION:

The demonstration site catchment area shown in Figure 18 was initially identified by overlaying a topographic map onto a map of the existing storm sewer system (from Boston Water & Sewer Commission) within West Roxbury. The basin outer boundary was first approximated as to gird the sewer system and then by observation of topographic divides all land area draining to the storm sewer system was included. As a check on the accuracy of the contour-derived approximation, an inspection during a storm event was conducted of the storm sewer lines near the periphery of the basin to ascertain the direction of flow at predicted outer boundary locations. Total catchment area was planimetered to be 207.2 acres (84 ha) with 46.5 acres (18.8 ha) draining into the quarry catchbasin. Since the quarry intermittently pumps water (usually only during business hours) the remaining 160.7 acres (65.2 ha) alone were considered to comprise the study's catchment area that imparts a runoff loading directly during a storm event. Roughly 66% of the wet weather contributary catchment area contains residential housing. The balance is idle or vacant open land.

Other characteristics of the urbanized portion of the catchment area are indicated below:

- street surfaced = 10.7 miles (17.1 km)(93% asphalt/7% concrete)
- street density = 0.10 lane-miles/acre (.06 km/ha)
- population density = 15 persons/acre (37.5 persons/ha)
- overall slope of area = 280 ft/mi 0.053
- portion of streets with swale ditches = 2%

- major sediment sources in catchment area: Quarry (pumping after rainstorm) (8:00 am - 5:00 pm)

---

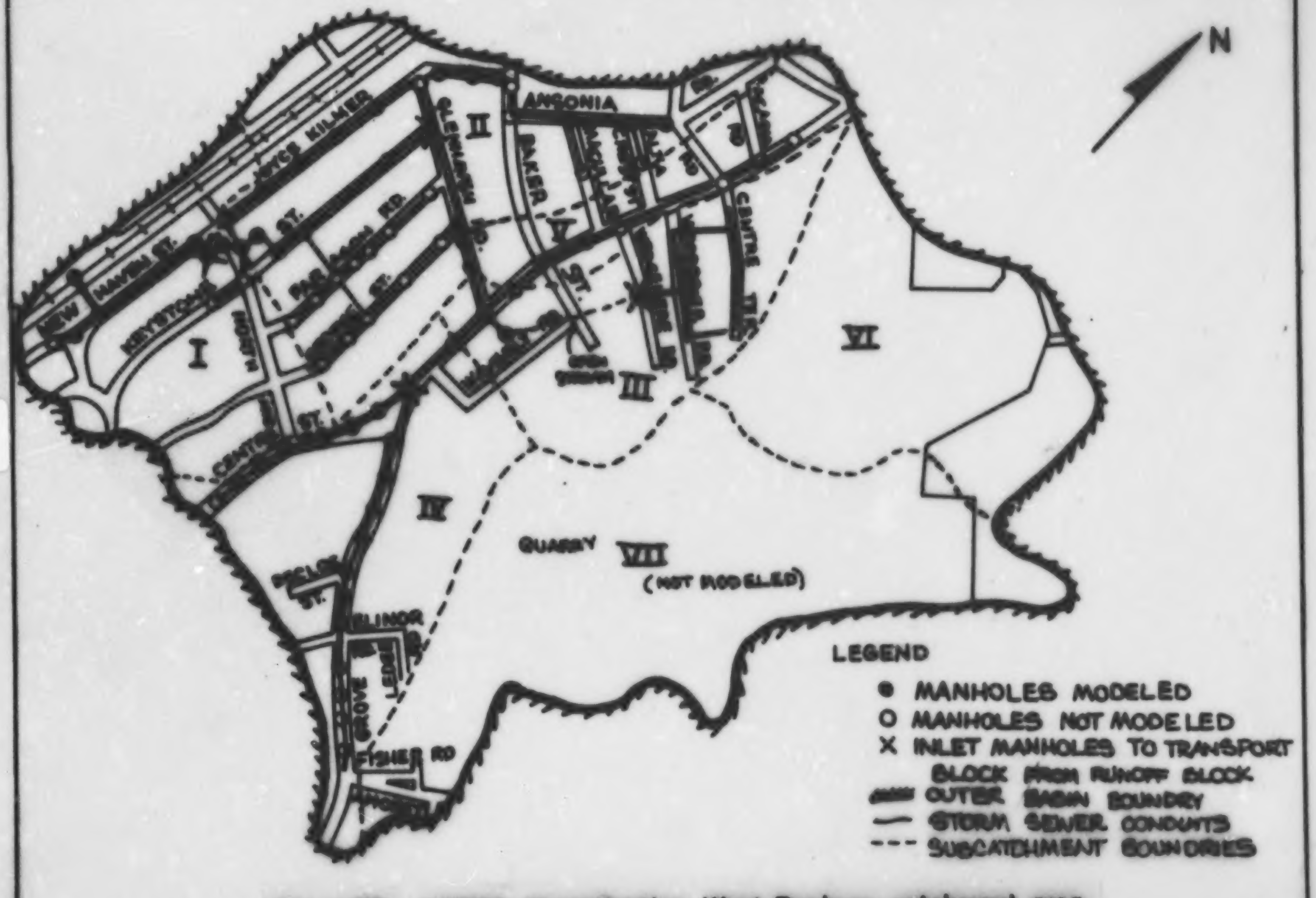
- No. catchbasins: 85
- Catchbasin density: 1.25 catchbasin/acre (.51 basin/ha)
- Average catchbasin dimensions:
  - a) sump volume = 65ft$^3$ (1.8 m$^3$)
  - b) total volume= 97ft$^3$ (2.7 m$^3$)
  - c) diameter = 4.25 ft (1.3 m)
  - d) depth = 7 ft (2.1 m)

## RUNOFF BLOCK DATA PREPARATION

In view of the relatively small size of the basin, and the homogeneity of basin land uses (essentially only single-family and open park land), a rough discretization grid composed of six subcatchments was selected as adequate for modeling purposes. (see Figure 19) With number of subcatchments chosen, individual subcatchment boundaries were delineated by the following criteria: sewer trunk line location; intra-basin topographical divides; homogeneity of land uses and ground slope characteristics; and subcatchment compactness.

Subcatchments I, II, III and V have a fairly uniform single-family residential land use pattern. Subcatchment IV is roughly half single-family residential and half open land. Subcatchment VI is entirely undeveloped land characterized by a steep gradient with a ground surface of shelf-rock. Subcatchment VII, draining into the West Roxbury Quarry, was not modeled, for quarry water is pumped only intermittently to the storm sewer system and was not pumped during the storms monitored for modeling.

Readily determined SWMM Runoff Block data for each subcatchment were as follows: area slope, characteristic width, land use % imperviousness. Ground slopes and characteristic widths were approximated by procedures described elsewhere. (30) Other data required for entry into the Runoff Block such as overland flow resistance factors, retention depths, infiltration rates, and infiltration rate decay coefficients were not available. These factors were assumed to vary from the default values pre-programmed into the model and were used as secondary calibration parameters.



N
NEW
HAVEN ST.
JOYCE KILMER
KEYSTONE
ST.
GLENHAVEN RD.
ANSONIA
BAKER
ST.
CENTRE
CENTRE TER.
ELINOR
FISHER RD
GROVE
I
II
III
IV
V
VI
QUARRY
VII
(NOT MODELED)
LEGEND
● MANHOLES MODELED
○ MANHOLES NOT MODELED
× INLET MANHOLES TO TRANSPORT BLOCK FROM RUNOFF BLOCK
OUTER BASIN BOUNDRY
— STORM SEWER CONDUITS
--- SUBCATCHMENT BOUNDRIES

Figure 19. SWMM discretization, West Roxbury catchment area.

## STORM SEWER MODELING & TRANSPORT BLOCK DATA PREPARATION

Of roughly 130 in-stream sewer elements (manholes and conduits), 41 main-stem elements were selected for Transport Block simulation. After numbering of modeled elements in network configuraton sewer maps were used to determine diameter, slope and length. Sewer slopes were calculated as differential manhole invert levels over length of connecting conduit. Manning roughness coefficients of roughness were assumed to be in the range of 0.014 to 0.015 except for an open brook section where a value of 0.035 was used.

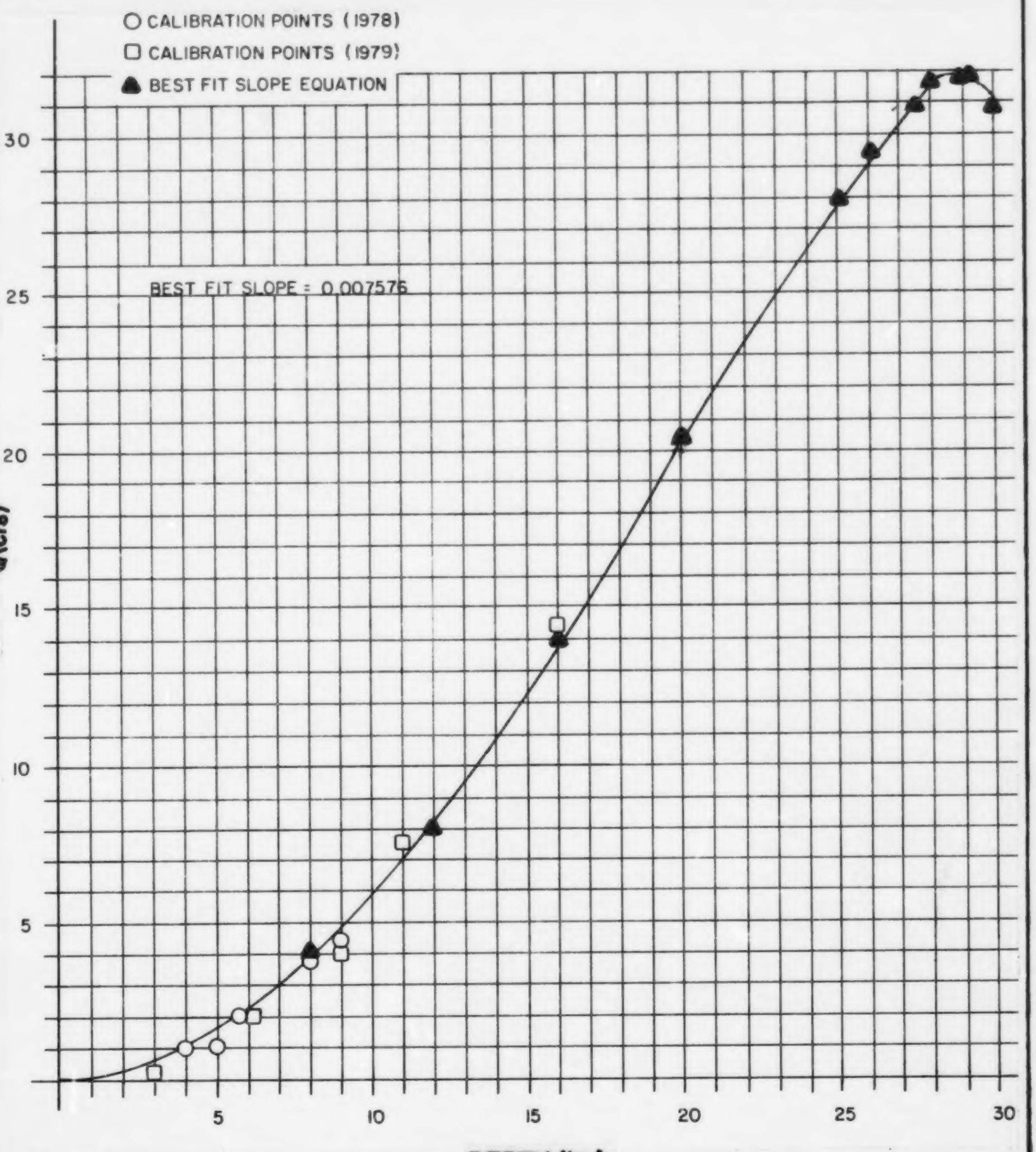
## CALIBRATION & VERIFICATION

For design objectives, SWMM can be an accurate productive tool for storm-event simulation when: extensive data defining basin-specific parameters are available; extensive testing is done to determine site specific substitutions for general default values offered in SWMM; rain gauging is conducted at or near the centroid of the drainage basin (and preferably at other locations in the basin as well); and, the full capacity of the Runoff (200 subcatchments) and Transport (159 sewer elements) Blocks are used.

Flow calibration was accomplished by adjusting calibration parameters to match both the sum of predicted and measured total volumes and the sum of predicted and measured flow peaks. The former criteria is achieved by adjustment of subcatchment percent imperviousness values the latter criterion by either adjusting number of sewer elements modeled in Transport, changing Manning roughness coefficient values for Transport Block elements, or by adding/subtracting an artificial conduit inducing further routing delay and thus attenuating /increasing peaks.

## STORM EVENT MONITORING

A raingage had been placed on top of the Spring St. West Roxbury Post Office, outside the outer boundary of the basin, and at a distance of roughly 1 mi (.6 km) from the centroid of the drainage basin. Rainfall intensities, for entry in 15 minute hyetograph time-steps in the Runoff Block, were read directly. A Manning liquid-level automatic recorder was placed at the end of the catchment area on New Haven Street to measure storm event depth of flow for a three month period. Time of travel tests were performed at varying depths of flow to enable calibration of a stage-discharge rating curve (see Figure 20). This curve was determined via a least-squares fitting procedure (31).



1 in = 2.54 cm

1 cfs = 28.3 l/s

**Figure 20. Stage/rating curve, 30 in. RCP drain, New Haven Street.**

It is desirable to embody a number of storm events for calibration supplemented with a smaller independent storm event set for verification, both storm sets being representative of typical variations in intensity and deviation. Unfortunately the three month monitoring period was dry and only two storms of reasonable volume were monitored. Table 6 presents a characterization of those storm events.

TABLE 6. MEASURED STORM EVENTS

| Date | Storm# | Duration Length of (hrs.) | Maximum Intensity (in./hr) | Total Rainfall (in.) | Comments |
|---|---|---|---|---|---|
| 7/4/78 | 1 | 17 | 0.14 | 1.08 | Most reliable data set |
| 5/16/78 | 2 | 3 | 0.33 | 0.5 | Less reliable data set difficulties encountered interpreting raingage data |

(1 in. = 2.54 cm)

## CALIBRATION/VERIFICATION METHODOLOGY & RESULTS

The primary objective of applying the SWMM Model was to derive a reasonable overall estimate of the basin's composite runoff coefficient, from which swirl regulator design flow frequencies can be estimated. Unfortunately, the paucity of storm event data for modeling necessitated a modification of the more desirable calibration/verification approach cited above. Storm event #1 was selected as a primary calibration storm and storm #2 as a secondary calibration storm.

Three calibration runs were made. For the first run, parameters were estimated based on the initial schematization of the basin. Adjustments for the second run were derived from volume and peak comparisons of Run 1 where only the primary calibration storm was used. Alteration of calibration parameters for Run 3 were based on volume and peak comparisons of Run 2 reflecting both calibration storm results.

A tabulation of parameter changes for the three calibration runs for the two storm events are given in Table 7.

TABLE 7. SWMM MODEL CALIBRATION MODEL DATA

| STORMS & PARAMETER VALUES | | CALIBRATION RUN | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Event 1 (7/4/78) Primary Calibration | | | | |
| Event 2 (5/16/78) Secondary Calibration | | | | |
| COMPOSITE RUNOFF COEFFICIENT | | 0.376 (datuum) | 0.396 (+5%) | 0.468 (+18%) |
| SUBCATCHMENT IMPERVIOUSNESS (%) | 1 | 45 | 47 | 55 |
| | 2 | 45 | 47 | 55 |
| | 3 | 43 | 45 | 52 |
| | 4 | 27 | 29 | 40 |
| | 5 | 45 | 47 | 55 |
| | 6 | 20 | 25 | 34 |
| DETENTION (in.) DEPTH | | 0.03 | 0.03* | 0.03 |
| MINIMUM INFILTRATION RATE (in./hr) | | 0.30 | 0.10 | 0.52 |
| DECAY RATE COEFFICIENT OF INFILTRATION | | 0.005 | 0.005 | 0.00115 |

* Detention depths were varied in Run #2 for more pervious subcatchments, #4 and #6 from 0.03 in. to 0.02 in. (1 in. = 2.54 cm)

Figure 21 and 22 depict the modeled versus measured hydrographs for the two storm events of 7/4/78 and 5/17/78. Tabulations of the ratios of measured to predicted total volumes and peak flows for the two calibration events are presented in Table 8.

Run #1: An initial run of storm 1 incorporated a composite runoff coefficient of 0.376; the resultant modeled flows (as illustrated in Figure 21) closely matched measured flows, particularly during the first two-thirds of the storm event. Near the end of the storm, however, modeled flows tended to be lower than recorded flow. While most of the peaks were reasonably well matched, the under estimation of total volume warranted an increase in the composite runoff coefficient for Run #2.

Run #2: Both calibration storms were run. The runoff coeffcient was increased by 5% over Run #1 to 0.396 and the minimum infiltration rate decreased by 67%. Both changes were made to increase total predicted runoff volume. For both storms the peak flows were accurately modeled. Total modeled runoff still underestimated measured total runoff.

Run #3: In Run #3, the composite runoff coefficient was increased to 0.468, and infiltration calibration parameters returned to the default value recommended in the SWMM User's Manual. In both Runs 2 and 3, the percent imperviousness attributed to subcatchment VI was increased at a greater rate than those of the other subcatchments in order to more adequately simulate pervious runoff from the sloping shelf-rock type terrain. For storms 1 and 2, total volume were slightly overestimated while peak flows were over-estimated by 15%.

On the basis of storms 1 and 2 an extrapolation procedure was developed to optimize total value and total peak equalization of measured and predicted values. Calibration volume and peak flow summations for Run 2 and Run 3 were then compared and juxtaposed with corresponding composite runoff coefficients. (See Table 9). By linear extrapolation the composite runoff coefficients yielding unity ratios for total volume/total peak flows are 0.4466/0.3921 respectively. Consequently a mean value of 0.419 for the composite runoff coeffiicient was selected for incorporation in design flow formulations.

TYPING GUIDE SHEET

TABLE 8. - SWMM CALIBRATION RESULTS

| | STORM DATE | MEASURED TOTAL FLOW ($ft^3$) | MEASURED PEAK (CFS) | RUN 1 | | RUN 2 | | RUN 3 | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Predicted Total Flow ($ft^3$) | Predicted Peak Sum (cfs) | Predicted Total Flow ($ft^3$) | Predicted Peak Sum (cfs) | Predicted Total Flow ($ft^3$) | Predicted Peak Sum (cfs) |
| CALIBRATION STORMS | (1) 7/4/78 | 95,616 | 2.90<br>2.40<br>2.76<br>3.76<br>0.70 | 78,518 | 3.26<br>2.42<br>2.78<br>2.48<br>0.46 | 81,775.8 | 3.40<br>2.52<br>2.90<br>2.64<br>0.46 | 106,481 | 3.97<br>2.94<br>3.40<br>3.09<br>0.53 |
| | (2) 5/17/78 | 48,303 | 2.25<br>9.0 | --<br>-- | --<br>-- | 41,414.89 | 3.0<br>9.0 | 48,487 | 3.35<br>10.20 |
| SUMMATION OF CALIBRATION VOLUMES AND PEAKS | | Σ1 = 95,616 | Σ1 = 12.52 | | Σ = 11.4 | | Σ1+2=23.93 | Σ = 154,968 | Σ = 27.49 |
| COMPARISON TO MEASURED | | Σ1+2=143,919 | Σ1+2=23.77 | M/P=1.2178 | M/P=1.098 | Σ=123,190.70<br>M/P=1.1683 | M/P=0.993 | M/P=0.929 | M/P=.865 |

1 $ft^3$ = 0.028 cubic meter

1 cfs = 28.3 l/s

EPA-287 (Cin.)
(4-76)

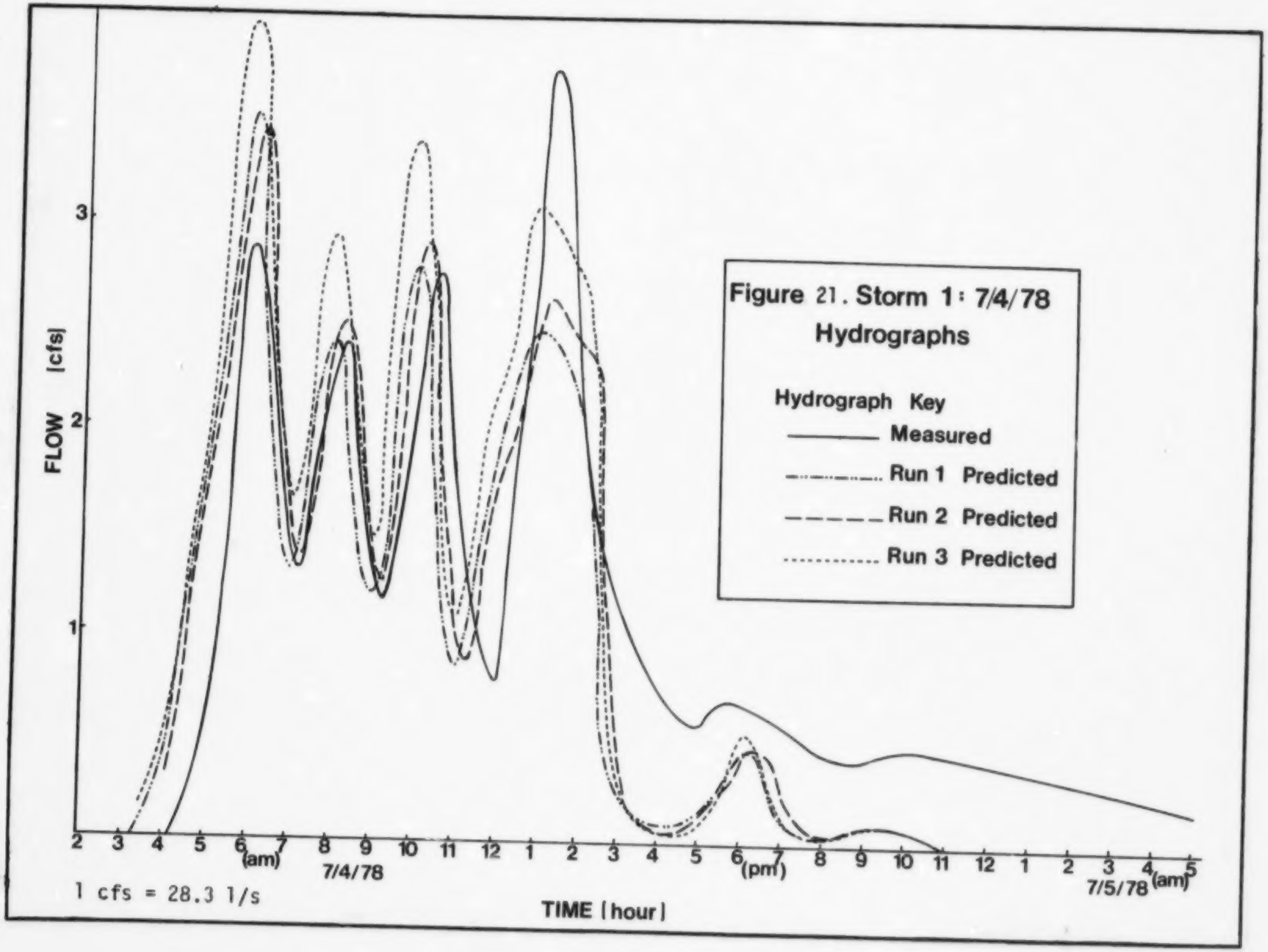


Figure 21. Storm 1: 7/4/78 Hydrographs

1 cfs = 28.3 l/s

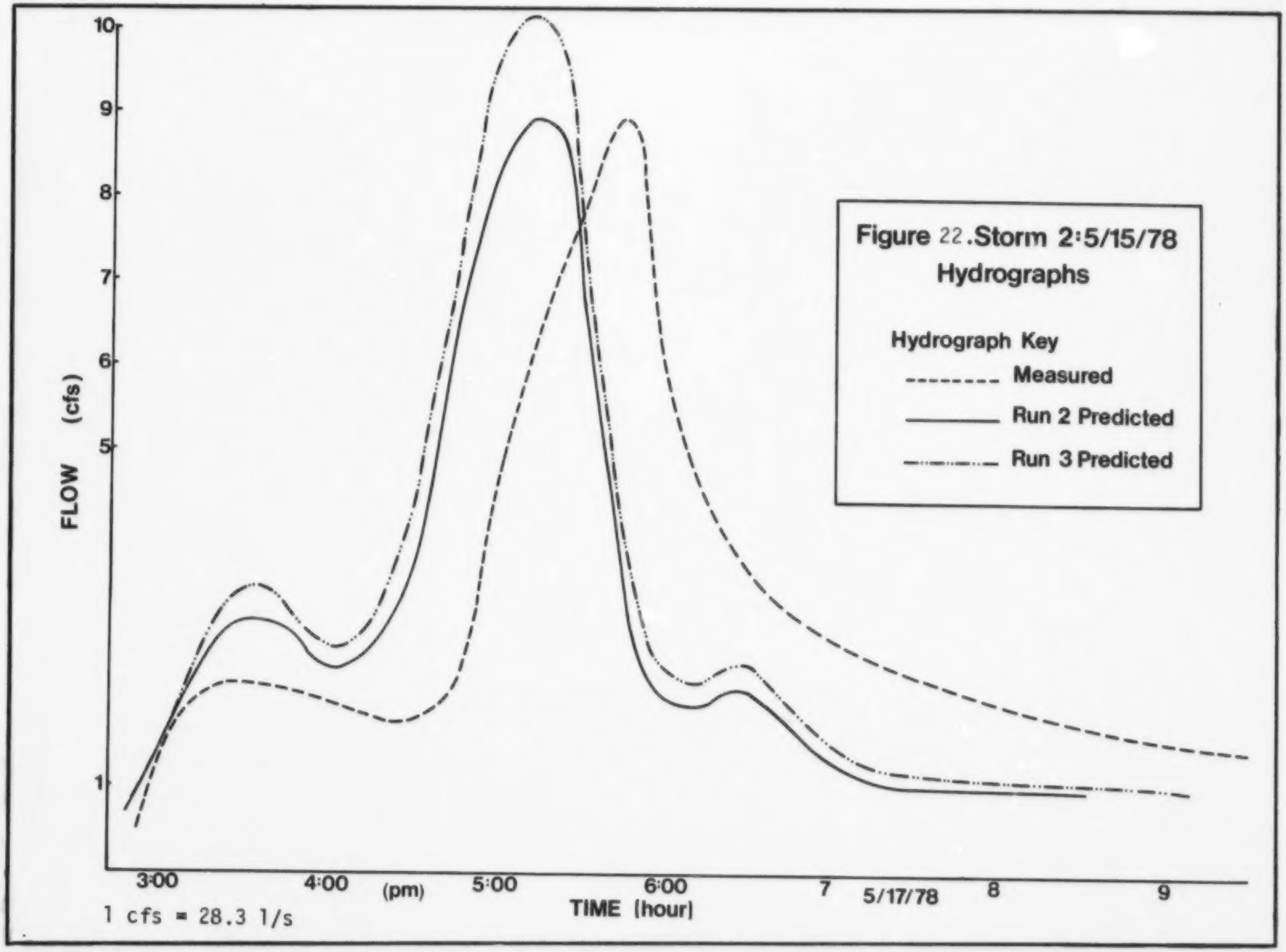


Figure 22. Storm 2: 5/15/78 Hydrographs

TABLE 9. EQUALIZATION OPTIMIZATION

| | RUN 2 | RUN 3 |
|---|---|---|
| Composite Runoff Coefficient | 0.396 | 0.468 |
| Sum of Peak Flows | 0.993 | 0.865 |
| Sum of Total Volumes (Using Parenthetic Values reflecting as well residual flows) | 1.168 | 0.929 |

# CHAPTER 7

# DESIGN PHASE - LANCASTER SWIRL PROJECT

## 7.1 FOREWORD

General design conditions and site characteristics are provided in sections 7.2 and 7.3, respectively. Rainfall/runoff considerations and selection of design flow for sizing the facility are given in section 7.4. Final Swirl Concentrator design details are given in section 7.5. Swirl Degritter design information is provided in section 7.6. Other facility features including chlorination and Discostrainer are cited in section 7.7. Finally, description of the Hydro-Brake used to control the foul sewer flow from the Swirl Concentrator to the Swirl Degritter during wet weather is given in section 7.8.

## 7.2 DESIGN CONSIDERATIONS AND CONSTRAINTS

There were many design aspects of the Lancaster Swirl project which required careful consideration and included the hydraulic sizing of the units as well as the sampling capabilities of the system in order to correctly evaluate the solids removal efficiency of the installation. Also, the general layout and design of the control building housing the Swirl Degritter and various electrical controls was an important consideration.

The constraints of the project design were minimal. In the Stevens Avenue drainage district, there was sufficient hydraulic head to drive the Swirl Regulator/Concentrator. If a Swirl is installed at the same elevation as an existing sewer, then either the influent line must be surcharged or the foul underflow be pumped. At the Stevens Avenue Swirl Project, the 60 in. (1.5 m) influent sewer is constructed on a steep slope mandated by the topography near the Conestoga River. This surcharging, or flooding, of the influent sewer, did not affect any upstream users, but did provide the driving force for the swirl unit. No problems were encountered with local land or soil conditions.

## 7.3 SITE CHARACTERISTICS

The Stevens Avenue Pumping Station and Swirl Regulator/Concentrator site is located in the southeastern corner of City of Lancaster and is east of South Broad Street and west of the Conestoga River (see Figure 18).

The Swirl facility site is approximately one acre (.4 ha) and consists of a gently sloping floodplain area. The site topography ranges from 268 to 294 ft (81.7 to 74.4 m) above sea level at an average slope of 4%. Soils are characterized as being a sandy clay alluvium, underlain with a shale-limestone at depths ranging from 14 to 19 ft (4.3 to 5.8 m). These soils are characteristic of the floodplain area in which the site is located. It is estimated that the 100-year frequency flood would cover the site to elevation 260 ft. (79.2 m). Therefore, the control building was constructed with a first floor elevation equal to the 100-year flood elevation to assure proper operation during major flooding stages of the Conestoga River.

## 7.4. HYDRAULIC DESIGN

The initial design phase for the Lancaster Swirl Project concentrated on the determination of the design storm flow, with consideration given to provide a unit which would operate at or above design capacity at least several times per year. One major purpose of this philosophy was to try to evaluate the swirl performance during flows greater than the design flow. For this reason and for economics, the swirl was sized to handle a design flow which would occur relatively frequently (5 to 10 times per year).

To determine this peak flow, the Rational Formula was used. This formula depends on the assumption of a steady, uniform rainfall intensity which will cause a maximum flow rate at the time of concentration, or the time of flow from the most distant corner of the drainage basin to the point of discharge. This maximum flow is found using the rational formula,

$$Q = C\,I\,A$$

where Q = peak runoff rate, cubic feet per second (cfs)

C = dimensionless runoff coefficient, expressing the ratio of rate of runoff to the rate of rainfall

I = average intensity of rainfall lasting for the time of concentration (in/hr)

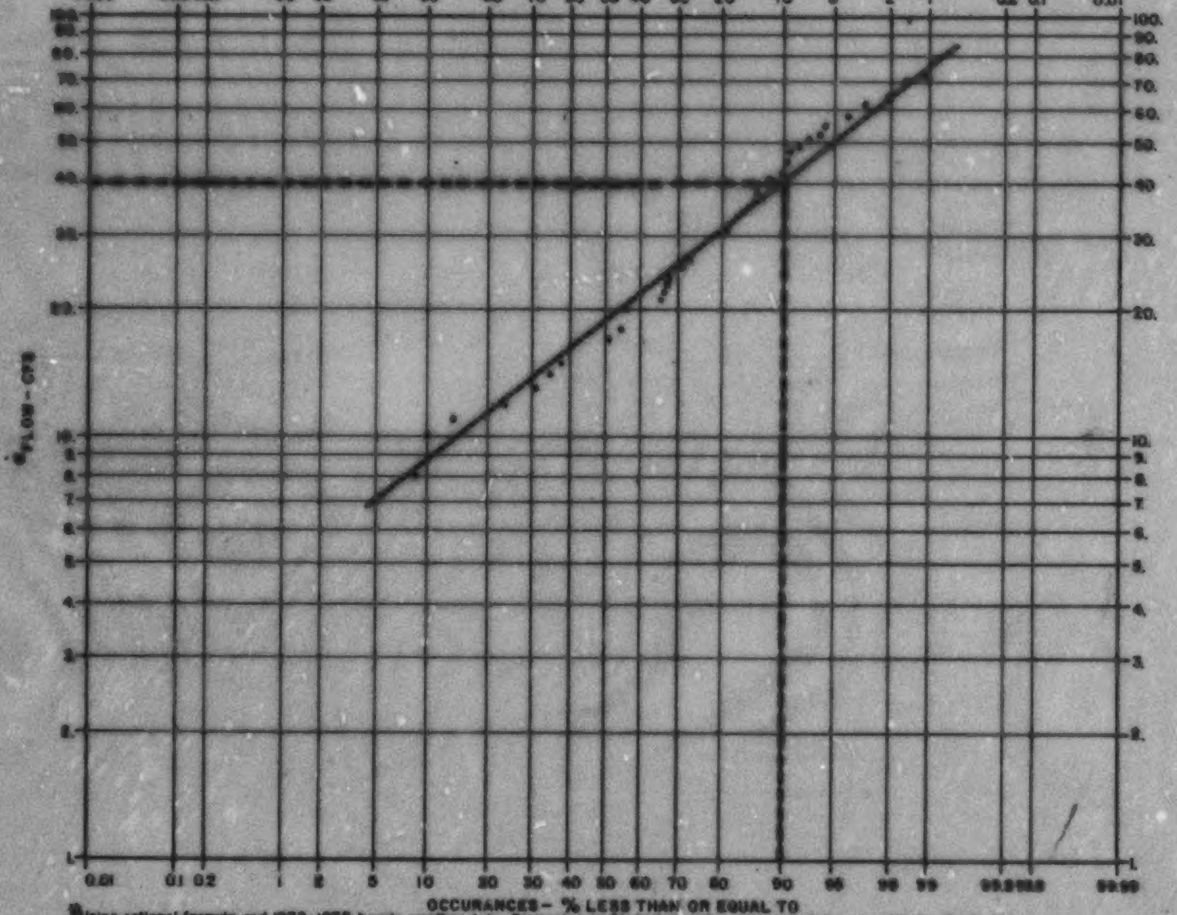
A = drainage basin area (acres)

The runoff coefficient (C) is estimated according to the soil surface available, the amount of development in the basin and the topography. For the Stevens Avenue drainage area, the runoff coefficient was estimated for each minor drainage section and a composite value of 0.55 was calculated.

Hourly rainfall data from the Pennsylvania State University weather station at Landisville for the three-year period from January 1973 through December 1975 were used as base data for the design flow determination. During the three year base data period there were 147 rainfall events which would have caused an overflow to the Conestoga River at the Swirl project site. All rainfall intensities less than 0.1 in./hr. (2.5 mm/h) which produced a runoff rate of less than 8 cfs (226 l/s) were assumed to be controlled without bypassing the Stevens Avenue Pumping Station. Flow rates which were assumed to have caused an overflow into the swirl site were correlated for the 147 rainfall events and plotted on the probability graph shown in Figure 23. Of these 147 overflow events, 20 events or 6.67 events per year, produced a runoff rate in excess of 40 cfs (1,131 l/s). A runoff rate of 40 cfs (1,131 l/s) was selected as the design flow for the swirl concentrator. From the probability analysis it is indicated that 127 of the 147 events or 90 percent of the rainfall events, would produce an overflow rate less than or equal to the design flow while 10 percent would be greater than the design flow. This will, on an annual basis, allow the Swirl Concentrator to process approximately 50 storm events per year of which 10 percent would be in excess of the design flow. The Swirl Concentrator unit is designed to hydraulically accomodate flows to 125 cfs (3,534 l/s).

After determination of a design storm flow, the next step in the design was sizing the Swirl unit. U.S. EPA's design publication (4) was followed. Initially, the inlet pipe diameter ($D_1$) is set which, in this case, was 3 ft (0.91 m). This size was selected for maintaining a scour velocity for the unit. Assuming a desired solids recovery efficiency of 90% and a flow of 40 cfs (1,131 l/s), Figure 24 was used to determine the chamber diameter ($D_2$) of 24 ft (7.3 m). Following this, Figure 25 was used to check the estimated 90% settleable solids removal efficiency.

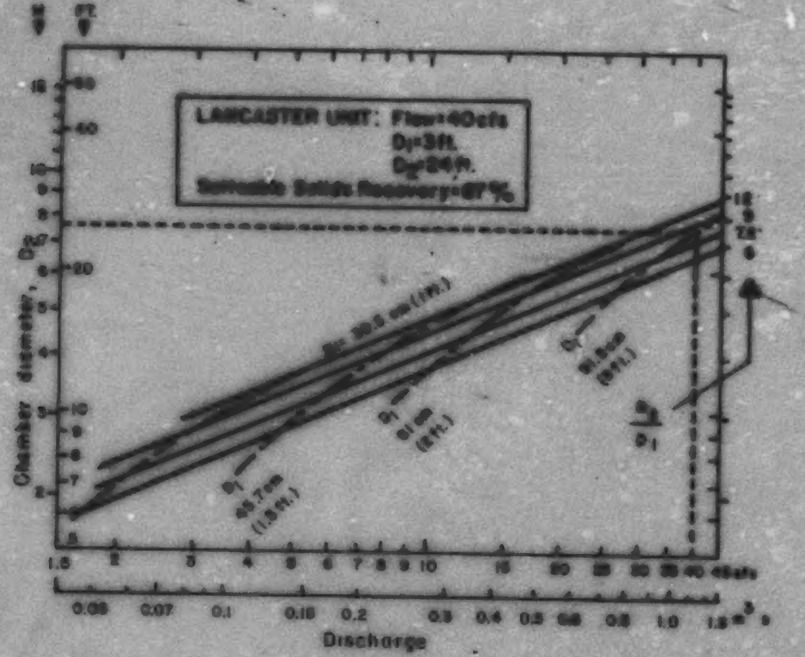
The remainder of the dependent dimensions are shown with the necessary design equations on Figure 26. However, it should be noted that it was necessary to alter some of the radii ( $R_1$, $R_3$ and $R_4$ ) on the gutter lines so that a smooth curve resulted from scale-up of the unit. The axis



[a] Using rational formula and 1973–1975 hourly weather data - Pennsylvania State University research station, Landisville, Pennsylvania

1 cfs = 28.31

Figure 23 Calculated combined sewer flows at swirl site vs occurances-% less than or equal to.



$H_1/D_2 = 0.25$

Figure 24. Chamber diameters for 90% recovery.

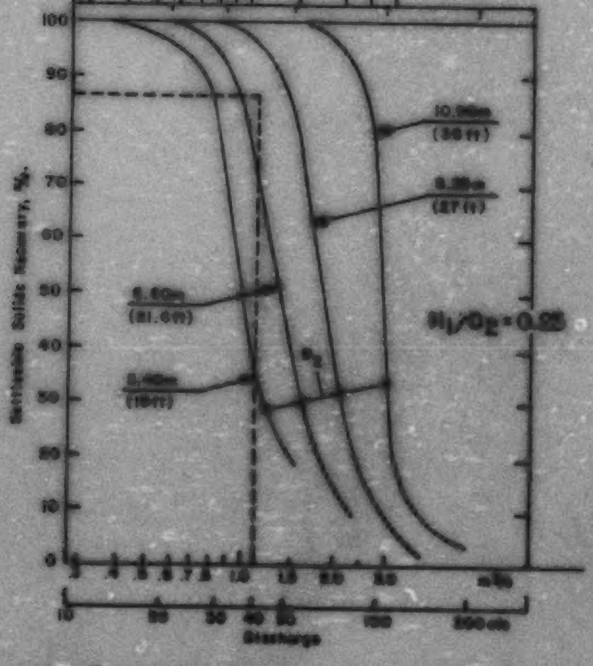
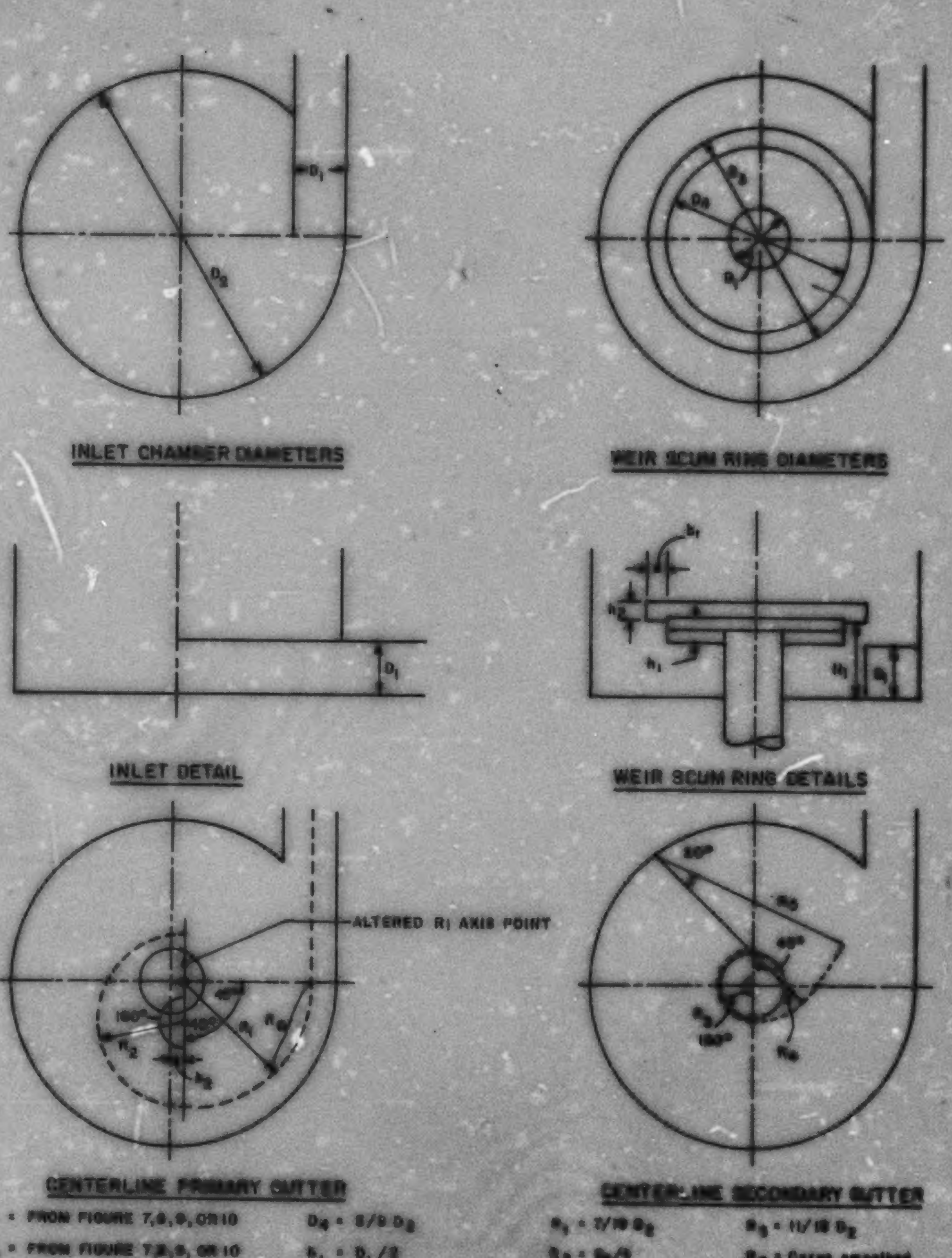


Figure 25. Settleable solids recovery for $D_1 = 91.5$cm.(3ft.)



D1
D2
D3
D4
ALTERED R1 AXIS POINT
40°
180°
R1
R2
R3
R4
R5
R6
h1
h2
H1
b1
b2
90°

INLET CHAMBER DIAMETERS

WEIR SCUM RING DIAMETERS

INLET DETAIL

WEIR SCUM RING DETAILS

CENTERLINE PRIMARY GUTTER

CENTERLINE SECONDARY GUTTER

*$D_1$ = FROM FIGURE 7,8,9, OR 10
*$D_2$ = FROM FIGURE 7,8,9, OR 10
*$H_1$ = $D_2/4$ OR FROM FIGURE 10
$D_3$ = 2/3 $D_2$
$D_4$ = 8/9 $D_2$
$h_1$ = $D_1/2$
$h_2$ = $D_1/3$
$b_1$ = $D_2/18$
$b_2$ = $D_1/6$
*Figures quoted are as presented in reference (2)

$R_1$ = 7/18 $D_2$
$R_2$ = $D_2/4$
$R_3$ = 5/48 $D_2$
$R_4$ = 3/16 $D_2$
$R_5$ = 11/18 $D_2$
$R_6$ = Curve smoothed in to meet inlet centerline

Figure 26. General Swirl Regulator/Concentrator design details.

for $R_1$ was offset to fit as shown in Figure 26. One omission from this figure in the original publication is the equation for determining the dependent dimension, $b_2$. After consultation with LaSalle Hydraulic Laboratories, this equation was determined to be $b_2 = D_1/6$. Table 10 shows the dependent dimension equations and the final values used for the Lancaster Swirl Project:

TABLE 10

ACTUAL LANCASTER SWIRL DIMENSIONS*

$D_1$ = 3 ft (0.91 m)
$D_2$ = 24 ft (3 m)
$H_1$ = 1/4 ($D_2$) = 6 ft (1.8 m)
$D_3$ = 2/3 ($D_2$)= 16 ft (4.9 m)
$D_4$ = 5/9 ($D_2$)= 13.3 ft (4.1 m)
$h_1$ = 1/2 ($D_1$) = 1.5 ft (0.46 m)
$h_2$ = 1/3 ($D_1$) = 1 ft (0.305 m)

$b_1$ = 1/18 ($D_2$) = 1.3 (0.41 m)
$b_2$ = 1/6 ($D_1$) = 0.5 ft (0.15 m)
$R_1$ = 7/18 ($D_2$)=10 ft (3.05 m)
$R_2$ = 1/4 ($D_2$) = 6 ft (1.8 m)
$R_3$ = 5/48 ($D_2$)= 2.67 ft (0.8 m)
$R_4$ = 3/16 ($D_2$)= 4 ft (1.2 m)
$R_5$ = 11/18 ($D_2$)=14.67 ft (4.5 m)

* These are actual dimensions and may slightly differ from the values determined from the equations.

Additional dimensions of the floatables trap, accompanying spoilers and weir plate were finalized following discussions with the U.S.EPA and LaSalle Laboratories. Following this basic hydraulic sizing of the swirl unit more in-depth design of the unit and the entire flow scheme was completed.

## 7.5. FINAL SWIRL CONCENTRATOR DESIGN CONSIDERATIONS

The final design included the preparation of plans and specifications for all unit processes comprising the Lancaster Swirl Project. These unit processes consist of the Swirl Regulator/Concentrator, the Swirl Degritter, the diversion box and the Discostrainer. Final design of the swirl unit included a pressurized flushing system for the purpose of washing down the unit following a storm event. The previous hydraulic studies demonstrated that as the storm flow receded, some residue would be left on the walls and floor of the Swirl because of diminished flow velocity. A flushing system was installed around the Swirl walls and under the overflow weir plate to insure proper cleanup following an event, washwater generated was discharged to the Stevens Avenue Pumping Station for conveyance to the City's South Treatment Plant.

There were a number of considerations for the final design of the total flow scheme, as shown on Figure 3, Chapter 1. The storm flow enters the diversion box through a 60 in. (1.5 m) diameter sewer. The flow passes through a manually-cleaned bar screen with 2-1/2 in. (6.4 cm) clear space between bars and into a 36 in. (0.91 m) diameter line through the control building and into the Swirl unit. At a storm flow of 125 cfs (3,534 l/s), the Swirl Concentrator is driven at its maximum capacity and the water surface elevation in the diversion box is 6 in. (15.2 cm) from the top. At this point a level sensor located in the diversion box actuates a sluice gate connected to the 60 in. (1.5 m) line to divert the flow in excess of 125 cfs (3,534 l/s) directly to the Conestoga River. Flow from the central and emergency overflows of the Swirl unit join this 60 in. (1.5 m) line into the river. The foul outlet flow is directed through a 12 in. (0.3 m) line to the swirl degritter which separates the grit and feeds the degritted effluent to the sanitary pump station.

The emergency overflow weir was included since the 40 cfs (1,131 l/s) design flow would be exceeded several times per year. This overflow can prevent severe overloading of the swirl by diverting the excess flow to the river. The emergency overflow was designed as a "window" in the Swirl walls so that flow would pass through the window and into a sloping trough. A weir plate in front of the window allows adjustment to vary the amount of head over the central overflow before any flow is directed to the emergency overflow. The range of Swirl Concentrator flows before the emergency weir flow is initiated can be selected from 55 cfs (1555 l/s) to 85 cfs (2403 l/s) The window weir consists of one quarter of the Swirl unit's perimeter.

During dry weather, domestic sewage is contained in the Swirl's primary gutter and is diverted directly to the Stevens Avenue Pumping Station without any flow going to the Swirl Degritter. During a storm event the rising water level in the Swirl unit is detected by a level sensor which closes the by-pass valve and opens the line to the Swirl Degritter.

Wet weather flow to the Swirl Degritter was initially controlled by a 12 in. (30 cm) pinch valve. The valve constantly malfunctioned and was then replaced with a Hydro-Brake. The

Hydro-Brake is a non-clogging flow restricting device with no moving parts (see section 7.8).

## 7.6 SWIRL DEGRITTER DESIGN DETAILS

It was decided during the design phase to size the Swirl Degritter to handle the dry weather flow if the City of Lancaster chose to do so. Therefore, the design flow for the Degritter was established as 3 cfs (84.8 l/s) from dry weather flow records. However, the flow is presently controlled at 1.2 cfs (3.4 l/s). The Swirl Degritter separates the grit which is then conveyed by a screw-feed/conveyor belt combination to a dumpster located on a scale to measure the amount of grit collected. The degritter effluent is cycled back to the Stevens Avenue Pumping Station for conveyance to the treatment plant. The Swirl Degritter design was performed following U.S. EPA design procedure (5).

The basic design parameters for the Swirl Degritter are an inlet, $D^*_1$, of 1 ft (3 m) design flow of 3 cfs (84.8 l/s) which represents the peak dry weather flow and a 90% settleable solids removal efficiency. (5) Figure 27 gives the general design dimensions and equations of the Swirl Degritter. From Figure 28 a chamber diameter, $D^*_2$ of 8 ft (2.4 m) was specified (5). It should be noted that the $D^*_3$ equation on Figure 27 has been revised to be $D^*3 = 2/3\ (D^*_2)^3$. This correction was made by LaSalle following the review of their design procedures. However, this revised $D^{*3}$ equation was not available until the design was complete. The general dimensions of the swirl degritter are shown in Table 11.

TABLE 11

ACTUAL SWIRL DEGRITTER DIMENSIONS

$D_1^* = 1$ ft (0.305 m) $H_1^* = 2\ D_1^* = 2$ ft (0.61 m)

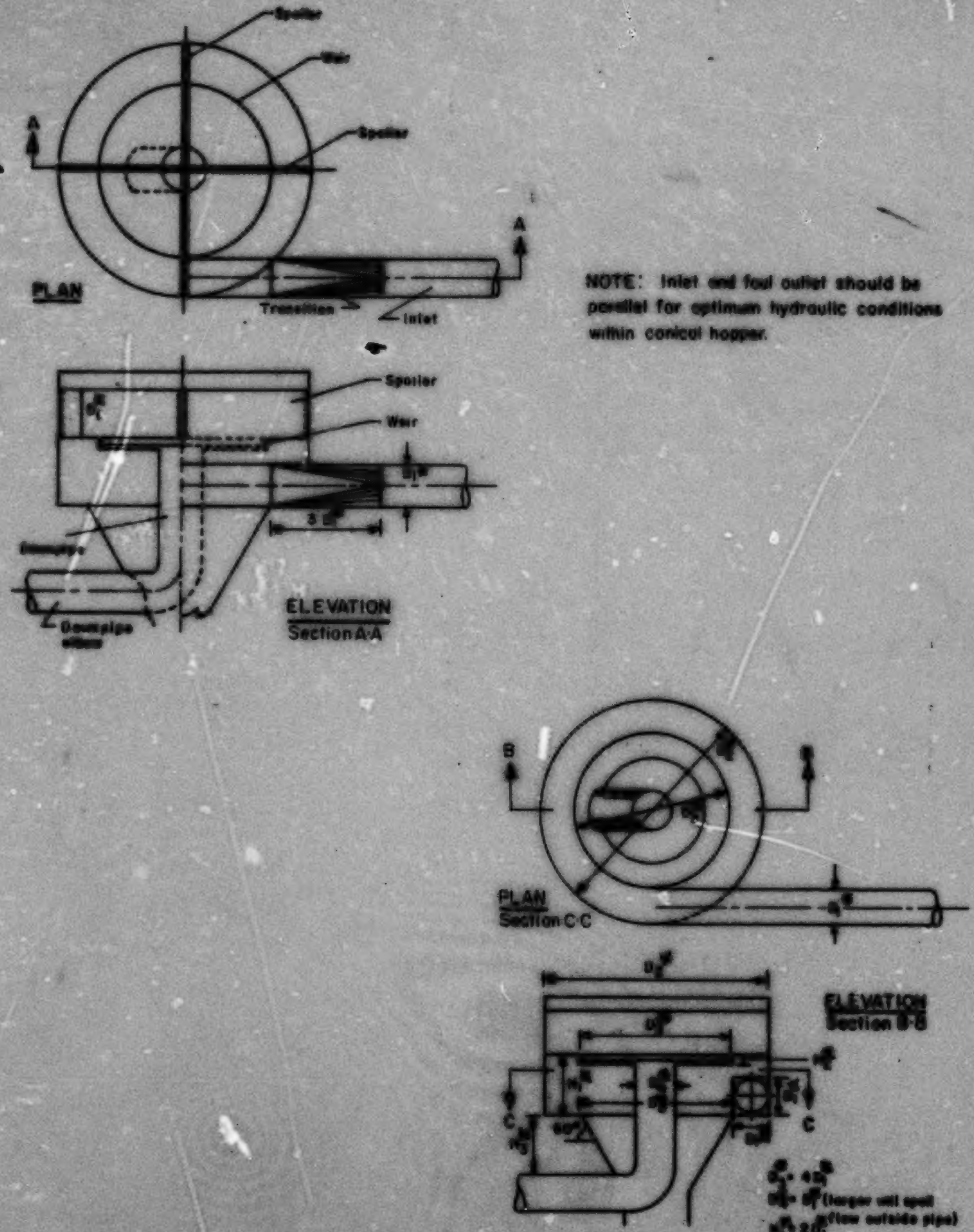
$D_2^* = 8$ ft (2.4 m) $H_2^* = 1/4\ D_1^* = 0.25$ ft (0.08 m)

$D_3^* = 4\ D_1^* = 4$ ft (1.2 m) $H_3^* = D_1^* = 1$ ft (0.31 m)
(old equation-actual dimension)

$D3^* = 2/3\ D_2^* = 5.3$ ft (1.6 m)(new equation - proper dimension)

## 7.7 OTHER FACILITY DESIGN FACTORS

Pre and post chlorination capabilities were required. Chlorine lines were installed to the diversion chamber and to the central swirl overflow. Flow proportional chlorine feed


Spoiler
Weir
Spoiler
A
A
PLAN
Transition
Inlet
Spoiler
Weir
$D_1^*$
3 $D_1^*$
Downpipe
Downpipe elbow
ELEVATION
Section A-A
B
B
$D_2^*$
$D_3^*$
PLAN
Section C-C
$D_1^*$
$D_2^*$
$D_3^*$
ELEVATION
Section B-B
$H_1^*$
$H_2^*$
$H_3^*$
60°
C
C

NOTE: Inlet and foul outlet should be parallel for optimum hydraulic conditions within conical hopper.

$D_2^* = 4D_1^*$
$D_3^* = D_1^*$ (larger will spoil flow outside pipe)
$H_1^* = 2D_1^*$
$H_2^* = 1/4D_1^*$
$H_3^* = D_1^*$ or larger
inlet translation=$3D_1$

Figure 27. General Swirl Degritter design dimensions.

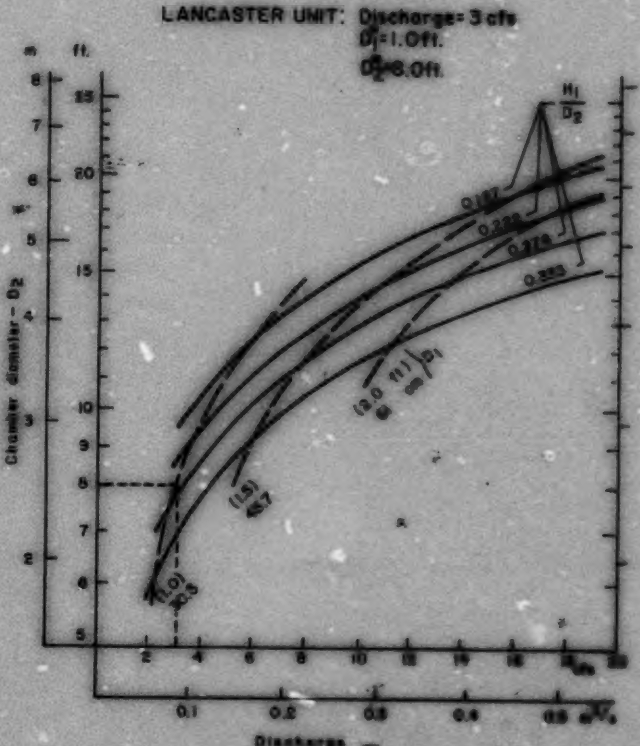


Figure 28. Chamber diameters for 90% recovery.

facilities were provided to permit chlorination at a dosage proportional to flow rate. A Discostrainer unit was also provided to treat up to 150 gpm (575 l/m) of the Swirl Concentrator foul outlet flow.

The 26ft x 32 ft (7.9 m x 9.7 m) control building for the project was also a major consideration due to the required area for the Swirl Degritter, the Discostrainer, various sampling equipment, electrical controls and laboratory facilities.

## 7.8 HYDRO-BRAKE

A Hydro-Brake is a patented flow controller made of stainless steel. It is self-regulating and has no moving parts. It requires no power, but uses the static head of stored water to operate its own "energy" to retard the flow. The movement of water through a Hydro-Brake involves a swirl action, dissipating energy to control the rate of discharge. Although the function of a Hydro-Brake is somewhat similar to an orifice, it has certain important advantages:

1. It permits a much larger opening for passage of the same amount of water. This is particularly important where clogging is a possibility, such as, for instance, in catch basins. It is also important where sanitary or combined sewage flows are being regulated.

2. The flow rate of a Hydro-Brake is not significantly affected by a variation in head. This is important where it is desirable to maintain a relatively large passage for the water, yet also maintain a fixed maximum rate of flow during peak conditions.

3. The outflow from a Hydro-Brake does not create a high velocity jet stream as an orifice will, thus avoiding scouring inside sewer pipe.

The Hydro-Brake was invented in Denmark about 15 years ago and is marketed in North America by Hydro Storm Sewage Corporation of New York. The Hydro-Brake must be designed for the specific application and flow condition. The design is patented and units are available only through the Hydro Storm Sewage Corporation.

The unit was designed to pass a maximum flow of 1.2 cfs (34 l/s). The unit was installed on the foul sewer line from the Swirl Concentrator.

# CHAPTER 8

# DESIGN - WEST ROXBURY FACILITY

## 8.1 Foreword

Site description is presented in section 8.2. Rainfall/runoff considerations and selection of design flow conditions are given in section 8.3. Dimensions of the Swirl Regulator/Concentrator and Helical Bend Regulator are given in section 8.4. Miscellaneous design details are given in section 8.5.

## 8.2 Site Description

A general discussion of the drainage area tributary to the demonstration facility was presented in Chapter 6. (see Figures 18 and 19) A plot plan of the facility was shown in Figure 4, Chapter 1. The 160 acre (64 ha) moderate income residential neighborhood is served by a completely separated sewer system, discharging through a 30 in (76.2 cm) drain to a 120 in. (305 cm) conduit connecting to the upper Charles River approximately 1200 ft (364 m) downstream. The 30 in. (76.2 cm) RCP drain flows southward along New Haven Street. Just prior to turning 90 degrees to connect to the intercepting drain, the 30 in. (76.2 cm) drain becomes 87 in. (221 cm) for about 210 ft (64 m) in length. The area behind the homes on New Haven Street is an open area. This open area is located between a line of trees separating the residential space and a factory building located on the opposite side of the interceptinfg conduit. The actual site within this open area is located on a former railroad bed. The railroad tracks and ties have long since been removed minimizing construction problems. The 87 in. storm drain to be used intercepts a 120-in. (305 cm) drain culvert just downstream of the site. The drain culvert is directly tributary to the upper Charles River.

## 8.3 Rainfall/Runoff-Design Flow Considerations

The original intent of the evaluation program was to monitor 15 storms over a 6 month evaluation period. A recurrence interval of 12 to 13 days (2 weeks) was chosen as a design flow consideration. In addition, the average maximum hourly flow was arbitrarily chosen as the statistic to consider in the recurrence interval considerations.

A design flow meeting the aforementioned criteria of 12 cfs (340 l/s) was computed from a rainfall/runoff analysis using the Rational Formula (see section 7.4). The analysis was performed using a "C" factor of 0.41 (see Chapter 6), a catchment area of 160 acres (64 ha) and a time series of maximum average hourly intensities for each of 361 rainfall events measured at the Blue Hills Observatory covering the spring-fall portions of a 10 year period. The resulting rainfall and runoff distributions are shown in Figure 29. Design flow for each unit was split evenly at 6 cfs (170 l/s). Maximum flow to each unit was established at 12 cfs (680 l/s).

## 8.4 Swirl/Helical Bend Design Dimensions

The Swirl Concentrator design formulation derived by APWA was used to size the facility. (4) A settleable solids efficiency of 80% was chosen to deliberately undersize or "over-drive" the facility since it would be treating stormwater.(See discussion in Chapter 6.2) Dimensions of the Swirl Concentrator are given in Table 12.

The design guidelines for the Helical Bend Regulator were consulted in developing the design dimensions (12). An inlet diameter of 1.5 ft (46 cm) was chosen by extrapolating the design curves below 10 cfs (283 l/s). Theoretical settleable solids removal is approximately 90%. Actual dimensions of the Helical Bend are given in Figure 30.

## 8.5 Miscellaneous Design Details

Although the Swirl and Helical Bend Regulators were both sized to have 1.5 ft (46 cm) inlet diameters, 2.0 ft (61 cm) diameter inlet and outlet overflow pipe sizes were used to minimize headloss. Piping configuration and sizes were shown in Figure 4, Chapter 1.

The right angle 8 in. x 10 in. (20 cm x 25.4 cm) Hydro-Brakes fabricated by Hydro Storm Sewage Corp. were designed to provide a constraining discharge of up to 0.18 cfs (5 l/s). This constraining discharge equals 3% of the design flow for the Swirl Concentrator and Helical Bend Regulator.

As can be seen in Figure 4, the foul sewer lines from both units discharge into a foul sewer tank with pumpage into either the 120 in. (305 cm) storm drain or into the 27 in. (68.6) VCP sanitary trunk sewer. Solids-carrying capacity of this sanitary sewer and segments further downstream were analyzed by computing average fluid shear stress conditions at half-pipe conditions. This condition was assumed since the sanitary sewerage system is separated but is severely impacted by clearwater inflow. Shear stress in the trunk sewer and downstream segments exceeded 0.06 lb/ft$^2$ (0.0026 kg/m$^2$) which is acceptable for self-scouring conditions (32).

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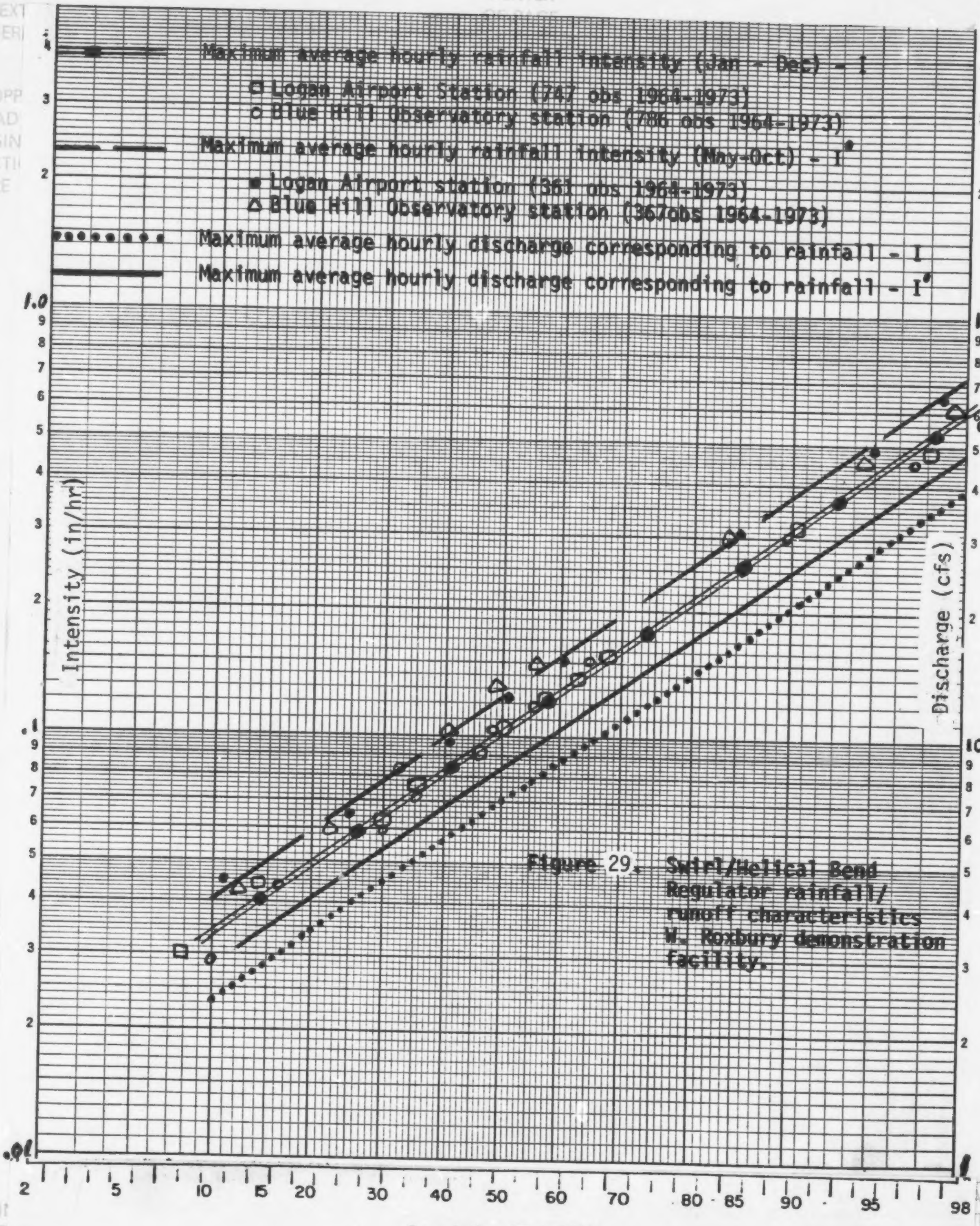

Figure 29. Swirl/Helical Bend Regulator rainfall/runoff characteristics W. Roxbury demonstration facility.

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R TABLES
AND ILLUS-
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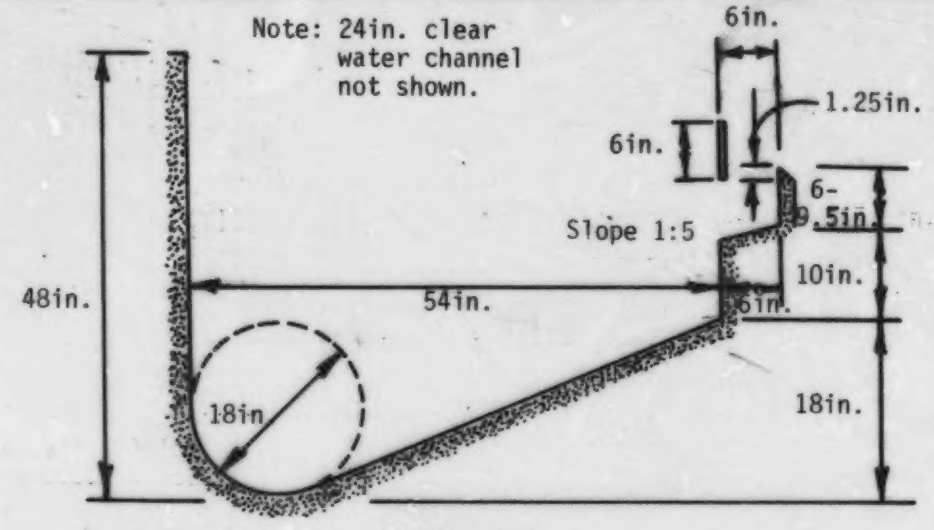
(4-76)

The various components of the installation and problems encountered affecting the design of the facility are discussed in Chapter 10. Instrumentation details are provided in Chapter 11.

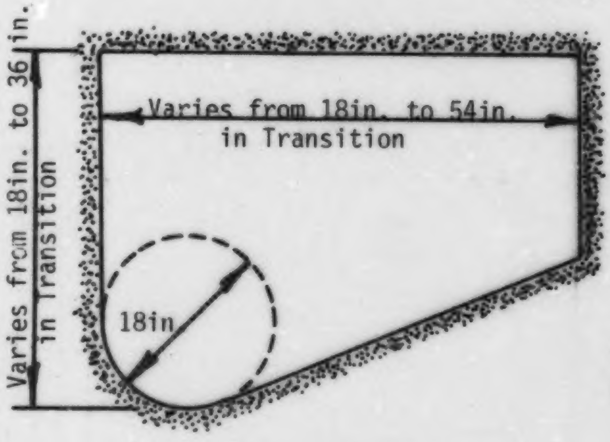
TABLE 12

Design Dimensions of
Swirl Concentrator
West Roxbury

| Dimension | (ft) | (m) | | (ft) | (m) |
|---|---|---|---|---|---|
| $D_1$ = | 1.50 | 0.46 | $R_1$ | 4.08 | 1.24 |
| $D_2$ = | 10.50 | 3.20 | $R_2$ | 2.63 | 0.80 |
| $D_3$ = | 6.93 | 2.11 | $R_3$ | 1.09 | 0.33 |
| $D_4$ = | 5.83 | 1.78 | $R_4$ | 1.97 | 0.60 |
| H1 = | 2.63 | .80 | $R_5$ | 6.42 | 1.96 |
| | | | $b_1$ | .58 | 0.17 |
| | | | $b_2$ | .50 | 0.15 |


Note: 24in. clear
water channel
not shown.
6in.
1.25in.
6in.
6-
9.5in.
Slope 1:5
10in.
48in.
54in.
6in.
18in
18in.

Section A-A


Varies from 18in. to 36 in.
in Transition
Varies from 18in. to 54in.
in Transition
18in

Typical Section B-B

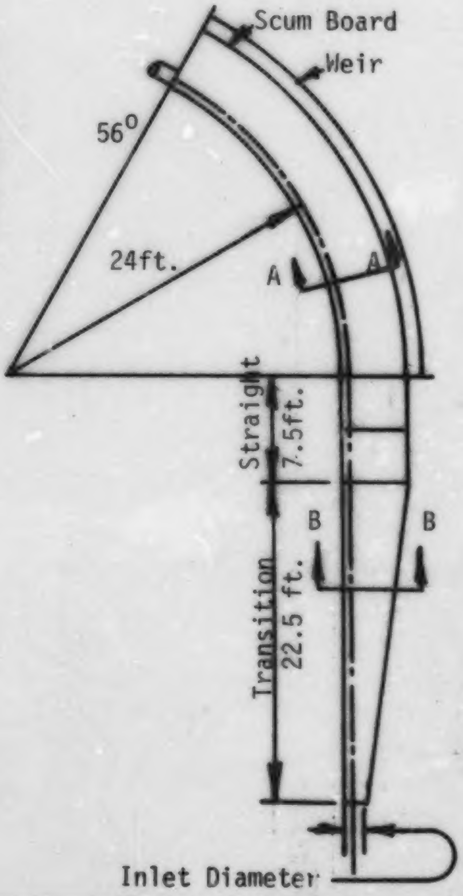

Scum Board
Weir
56°
24ft.
A
A
Straight
7.5ft.
B
B
Transition
22.5 ft.
Inlet Diameter

Figure 30. Helical Bend Dimensions,
W. Roxbury.

# CHAPTER 9
# CONSTRUCTION - LANCASTER PROJECT

## 9.1 FOREWORD

A general overview of the Lancaster swirl construction is presented in Section 9.2. Unique construction details are given in section 9.3. Project costs are provided in section 9.4. Instrumentation details are provided in Chapter 11.

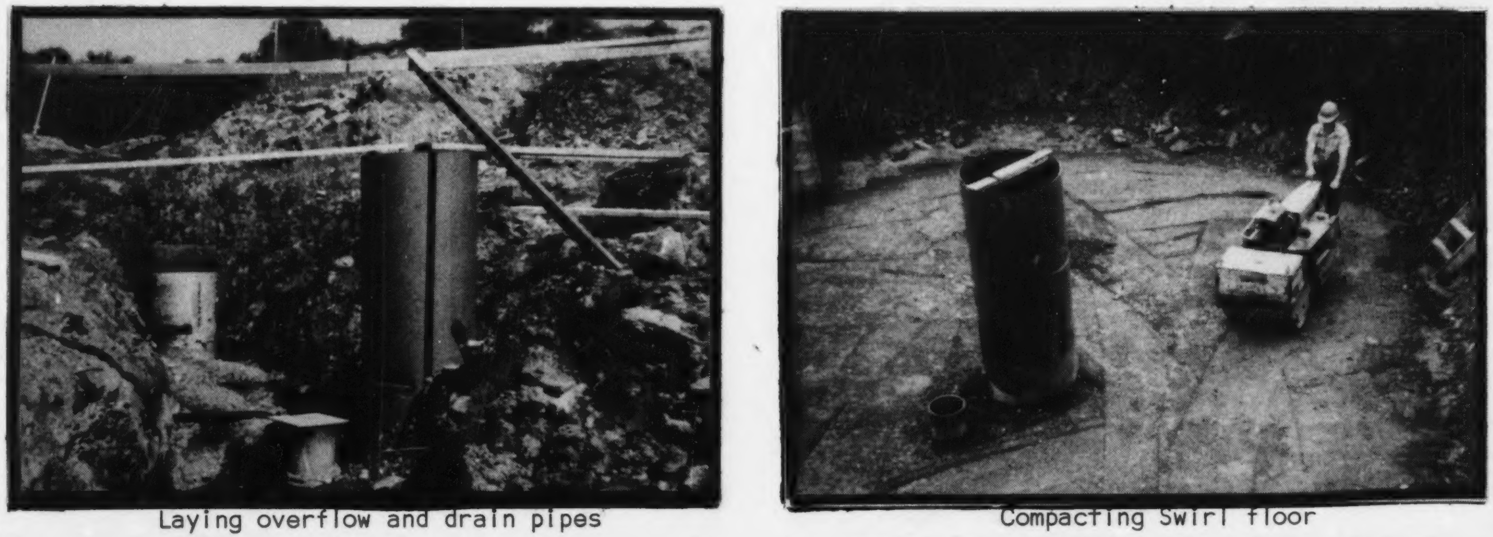
## 9.2 GENERAL

Design of the Lancaster Swirl Project was completed by Huth in late 1976. Construction bids were received in December 1976. Actual construction of the project began on April 13, 1977. Construction consisted of two contracts, one electrical and one general construction, which were essentially completed by June 1978 when the project was dedicated. Minor modifications were not completed until October 1978.

Following blasting at the site to facilitate rock removal, site excavation was completed and the drains for the central overflow, emergency overflow, foul outlet and various sampling lines were laid. After backfill and compaction, layout of the Swirl floor with radial reinforced steel began, as shown in Figure 31. It should be noted that the larger pipe in the foreground is the clear overflow, the shorter, smaller pipe is the foul outlet and the pipe in the background is the emergency overflow. Simultaneously, work progressed on the control building basement and the diversion chamber. Figure 32 shows a view of the Swirl site during construction and some scenes of the completed project. Generally, the construction proceeded smoothly, although there were a number of considerations which required special attention, as discussed below.

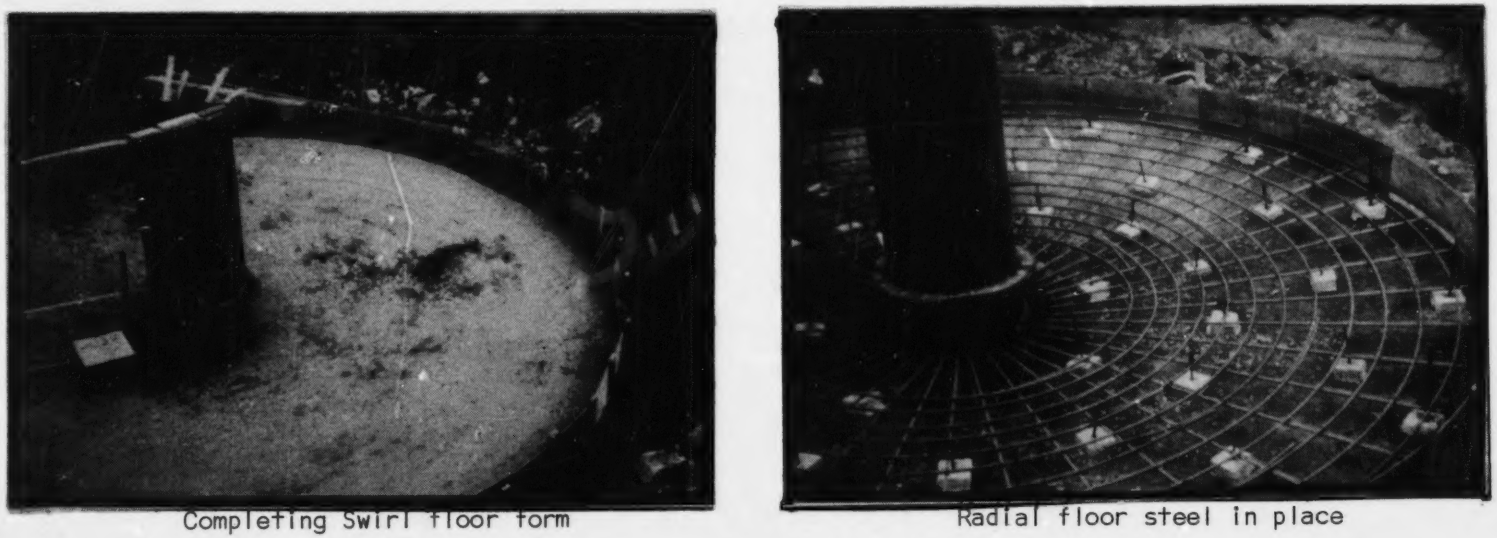
## 9.3 SPECIAL CONSIDERATIONS

One of the most difficult portions of the project was forming the gutters in the floor of the Swirl Concentrator. A large, level plywood platform was constructed on site and the necessary shape of the primary and secondary gutters was drawn on the platform with the assistance of a survey transit. After this curving shape was established, forms were constructed to the set depths of the gutters by cutting plywood to fit the curves on top and bottom with supports between. These forms were constructed in sections to ease placement on the Swirl floor as shown in Figure 33. The



Laying overflow and drain pipes

Compacting Swirl floor



Completing Swirl floor form

Radial floor steel in place

Figure 31. Initial construction.

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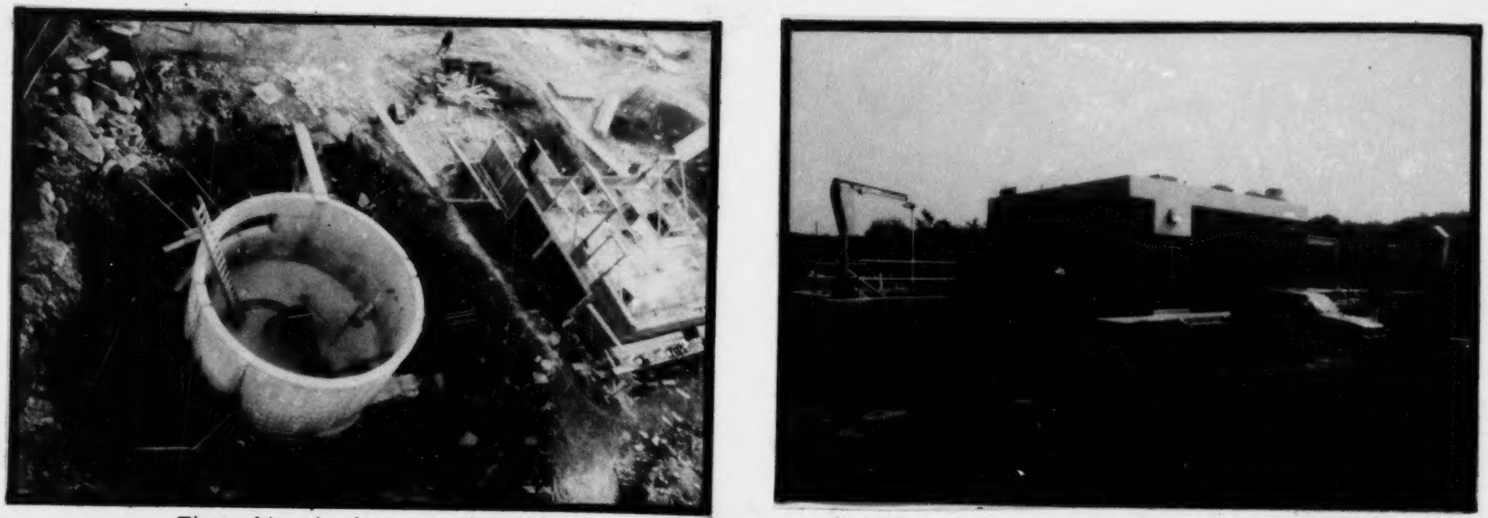
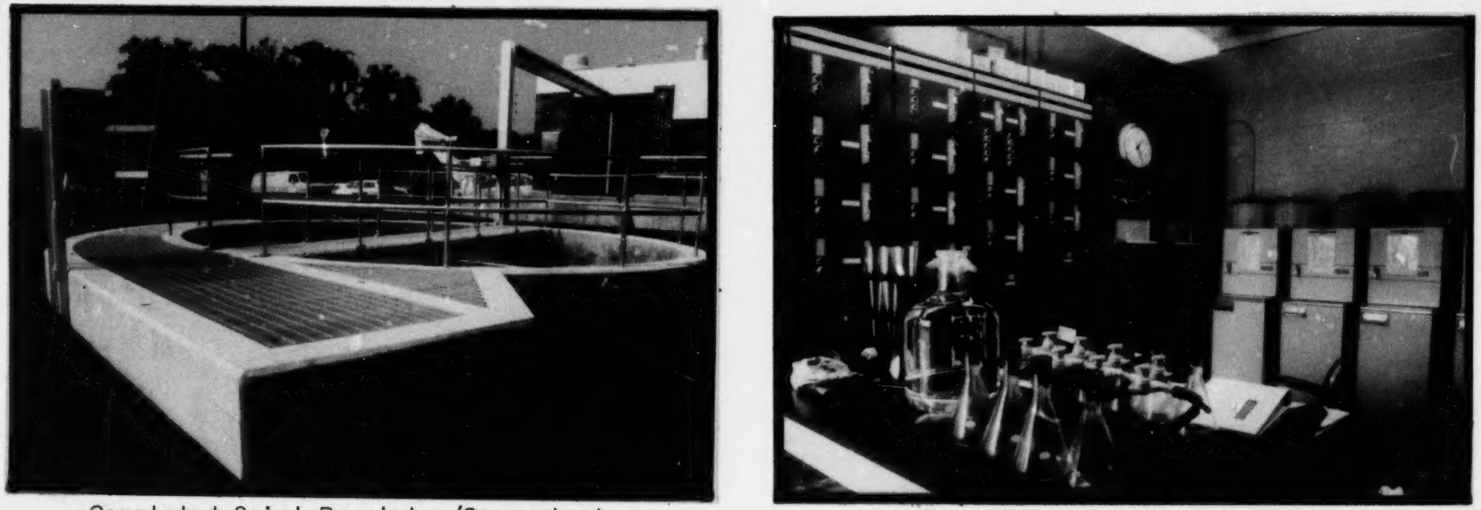
best available copy.



The site during construction

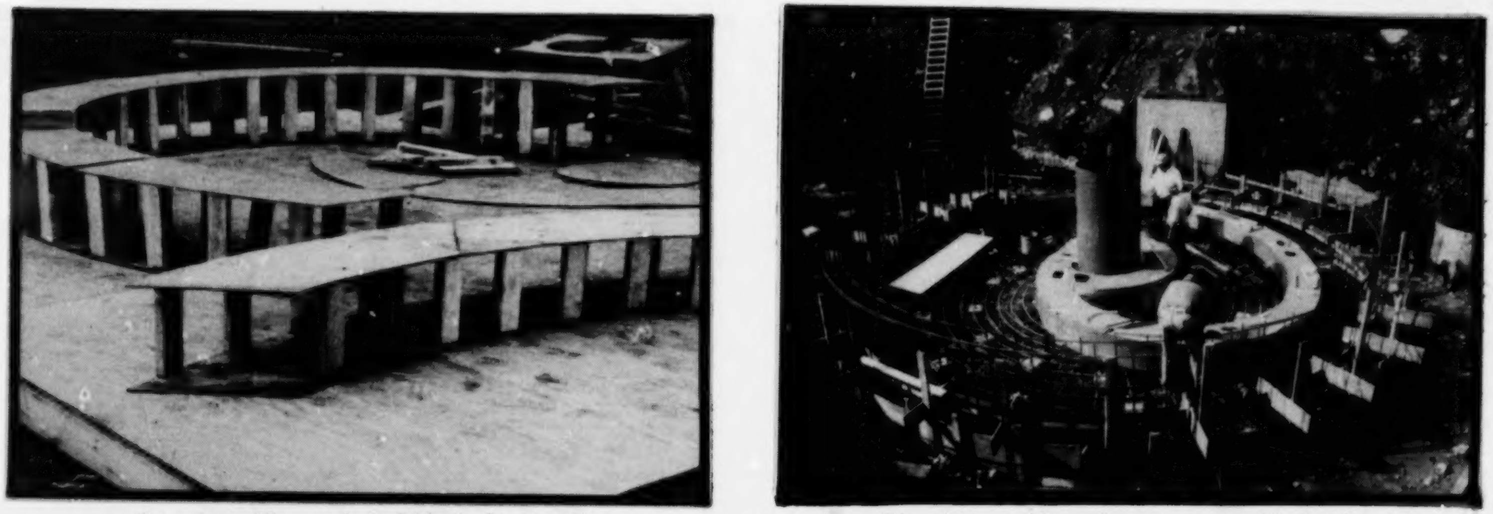
Completed Swirl Project



Completed Swirl Regulator/Concentrator

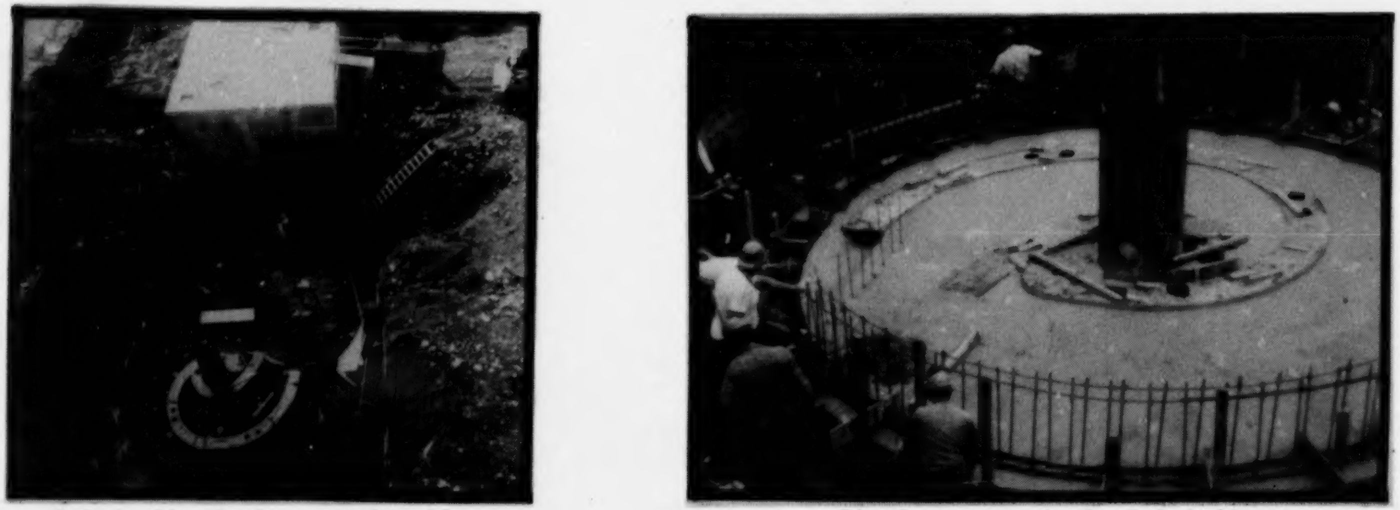
Top floor of control building

Figure 32. Lancaster Swirl Project.



Construction of initial formwork

Placing gutter forms on radial steel



Swirl site during construction

Placing concrete in Swirl floor

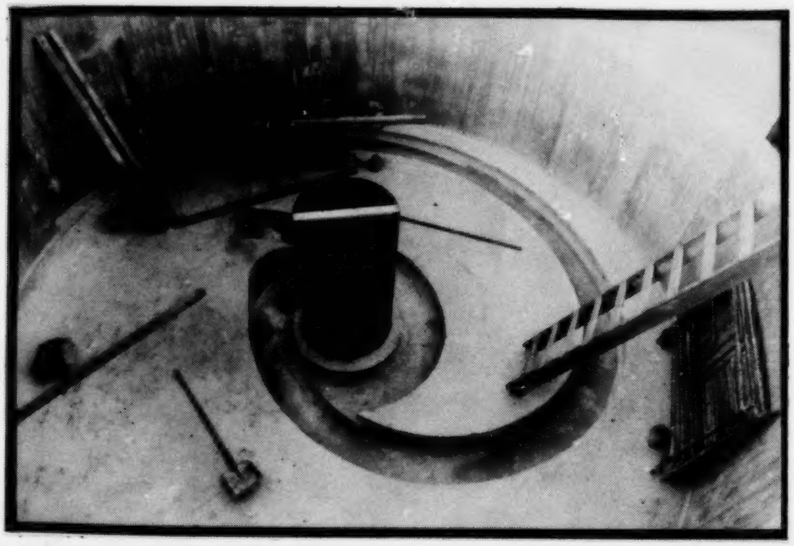
Figure 33. Swirl floor and gutter construction.

form sides were then sealed with sheet metal and laid in place on the radial floor steel. After the forms were placed, the concrete was poured and finished. The cross slope of the Swirl Concentrator floor was established at 1/4 in./ft (2.1 cm/m) to aid in solids removal during flushing after a CSO event. Figure 34 shows the final configuration of the forms and the definitive shape of the gutters. A rectangular gutter cross section was formed to simplify construction during placement of primary concrete. After forms were removed, the rectangular gutter was grouted to an hydraulically efficient semi-circular shape to reduce shoaling of solids.

Another consideration during construction was the inlet section to the Swirl unit. Flow enters the swirl tangentially and, therefore, required a suitable transition shape. In addition, U.S. EPA design specifications (4) required a square pipe while the inflow pipe was 36 in.(.91m) in diameter. Therefore, a circular-to-square transition piece was required. A free-standing flow deflector wall was constructed at the entrance to the swirl to break up any vortex motion in the unit. These inlet configurations are shown in Figure 35.

An emergency overflow was required so that overloading of the Swirl unit could be relieved by diverting the excess flow directly to the river. The overflow consisted of a slotted opening, or "window", in the concrete wall leading to a trough on the outside of the Swirl and finally to the 60 in.(1.5m) outlet pipe to the river. Flow over the emergency overflow weir could be measured at any time since a small weir and level sensor was placed in the bottom of the trough. The "window" weir was formed with a small pillar between the two sections and the total weir covered one-quarter of the Swirl's perimeter. An adjustable weir plate was placed on the inside of the unit to control the amount of flow over the central overflow. Figure 36 shows the two windows and the drain trough during construction.

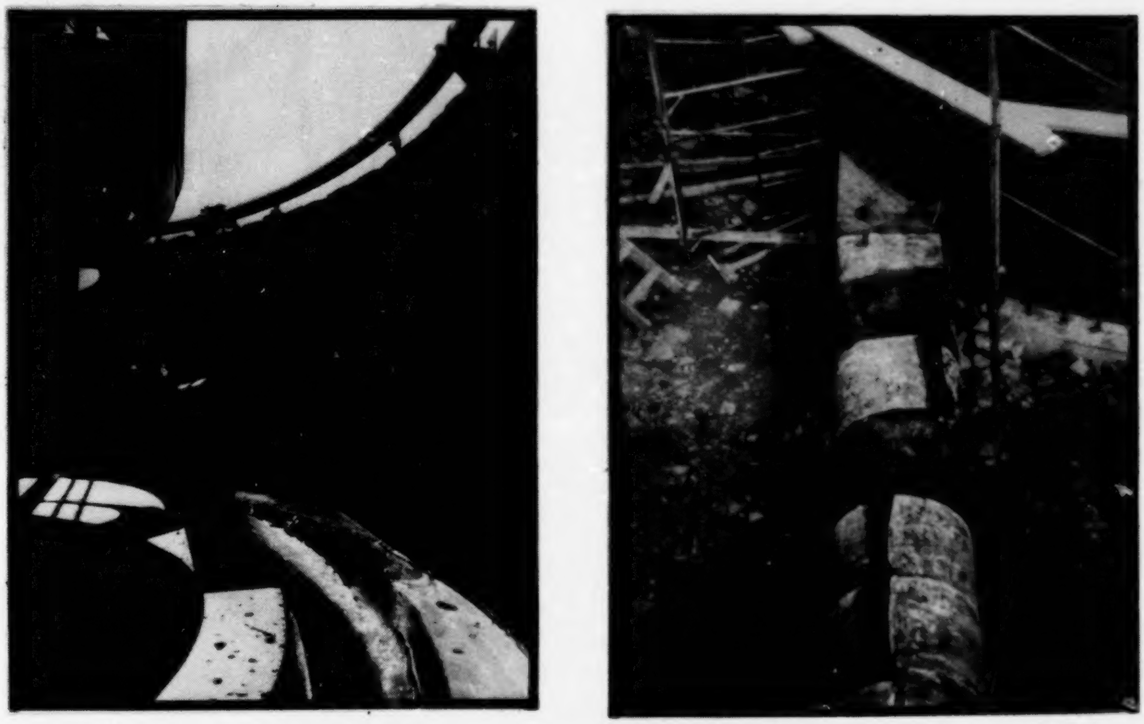
The prefabricated weir and floatables trap assembly, proved difficult to install because it was large and bulky, and required precise placement for correct performance. Also, in order to prevent any clogging of floating matter in weir plate supports, the mounting had to be performed from above. Four large 3/4 in. (1.9 cm) adjustable bolts suspended the assembly from the steel walkway, thereby eliminating any possible protrusions which could catch any floating matter. Figure 37 shows a view of this prefabricated assembly.



Finished gutters before grouting

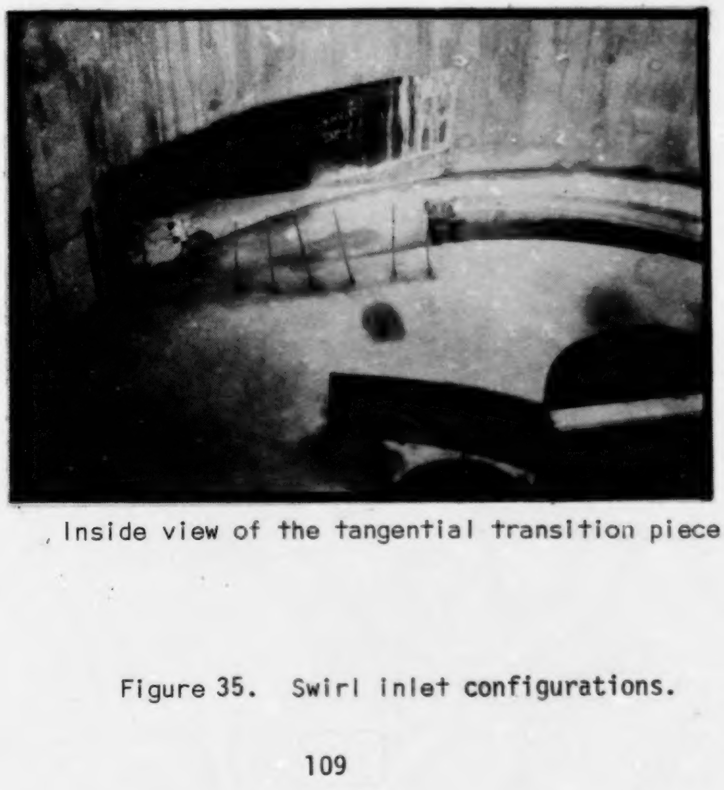
Grouting floor gutters

Figure 34. View of gutters in Swirl floor.



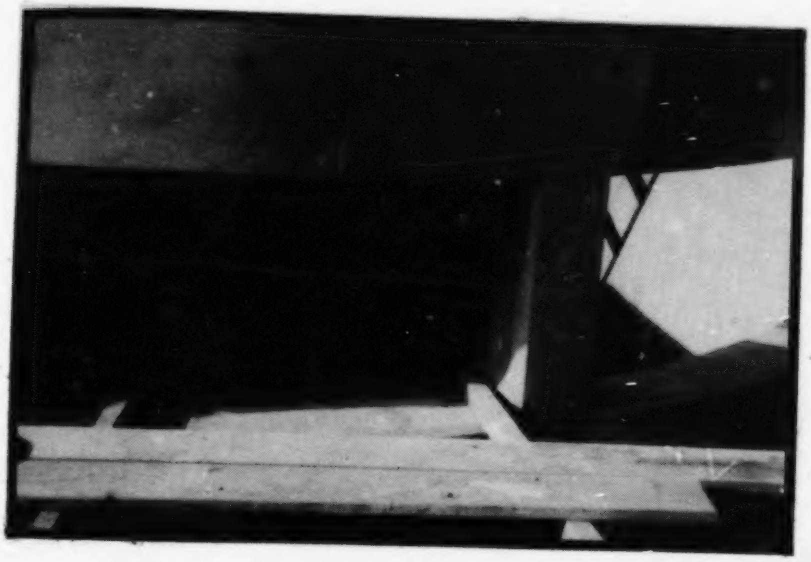
Concrete flow deflector

The circular-to-square transition



, Inside view of the tangential transition piece

Figure 35. Swirl inlet configurations.

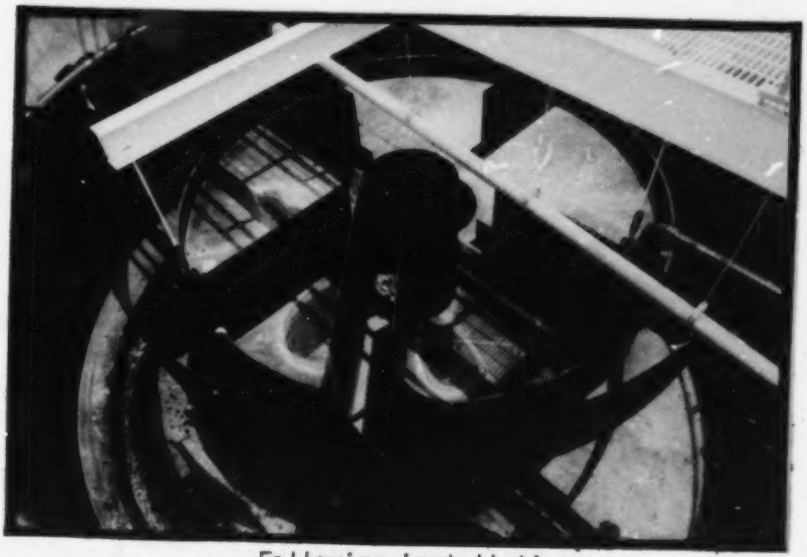


View through the weir window into Swirl unit

Construction of emergency overflow trough

Figure 36. Emergency overflow weir.

The prefabricated unit



Following installation

Figure 37. Weir and floatables trap assembly.

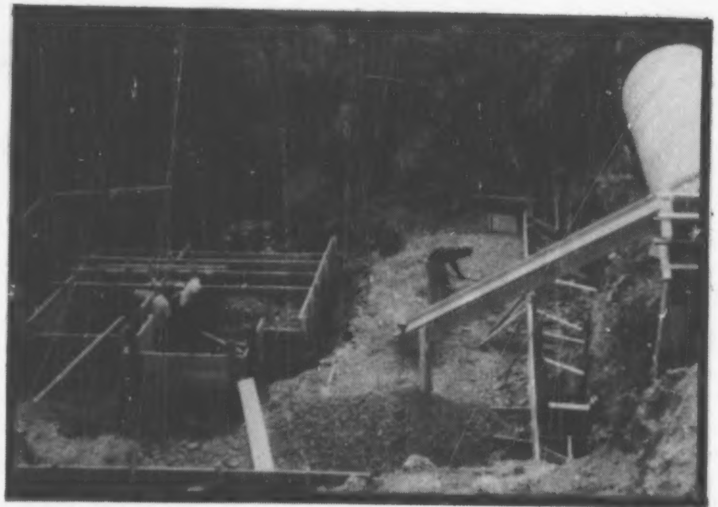
The remainder of the construction proved to be routine and presented no particular problems.

The Swirl Degritter was placed in the lower level of the control building before completion of the upper levels due to the size of the unit. The Degritter was installed in a lowered floor section to provide for easy observation and to provide sufficient head for gravity flow of the larger Swirl unit's underflow to the Degritter. A sump was provided in this lowered section for drainage. Figure 38 shows the control building floor, the Swirl Degritter and the grit handling system.

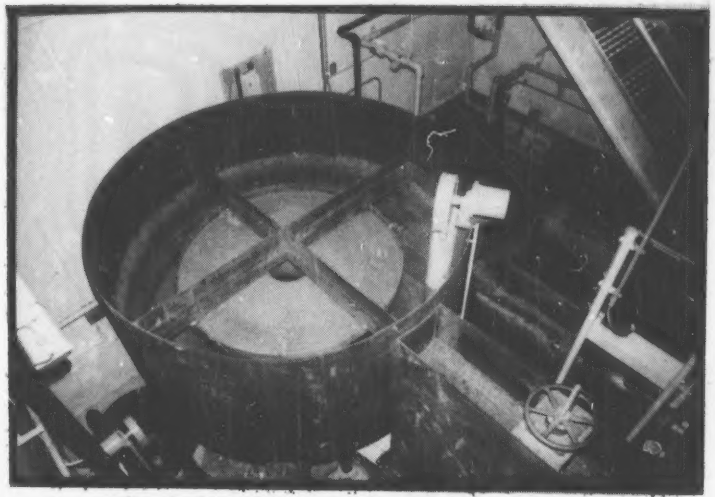
## 9.4 CONSTRUCTION COST

The total cost of the Lancaster swirl concentrator demonstration project was about \$1,100,000 (ENR 3000). In addition to the construction cost of the Swirl facilities, this cost includes inspection and administration, engineering, equipment, supplies, laboratory charges, operating salaries, utilities, repairs, and the project report.

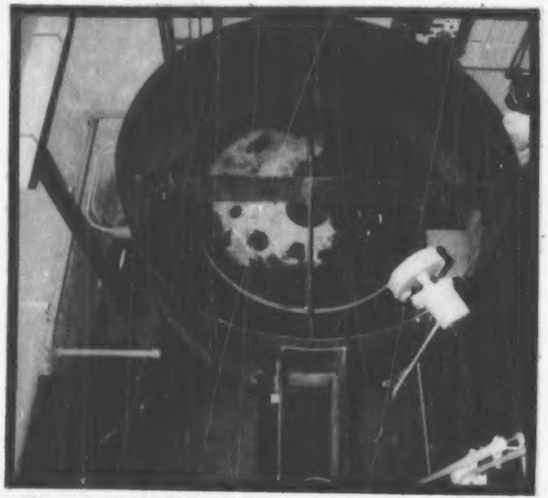
Construction of the Lancaster Swirl Project was divided into two contracts. Electrical work was done by Lancaster Electric Co. at a cost of approximately \$123,000. General construction work was performed by Toews, Ayres & Huber, Inc., a local contractor, at a final cost of approximately \$569,000. The construction costs of the Swirl facilities were estimated at about \$692,000 of which the Swirl Regulator/Concentrator cost was estimated at about \$168,000 or about \$6,500/mgd (\$148,000/$m^3$/s) of design capacity. The other construction costs include the Swirl Degritter and grit handling system, the control building, the instrumentation and the disinfection system. No land acquisition costs were incurred since the City of Lancaster already owned the project site. These figures also include a number of various change orders incurred due to first-time design and construction. Also, some extra costs such as the Discostrainer and extensive lab equipment were incurred for the latter evaluation work. Table 13 shows a breakdown of the general construction costs by contract amount. Table 14 presents a more condensed elaboration of construction costs:



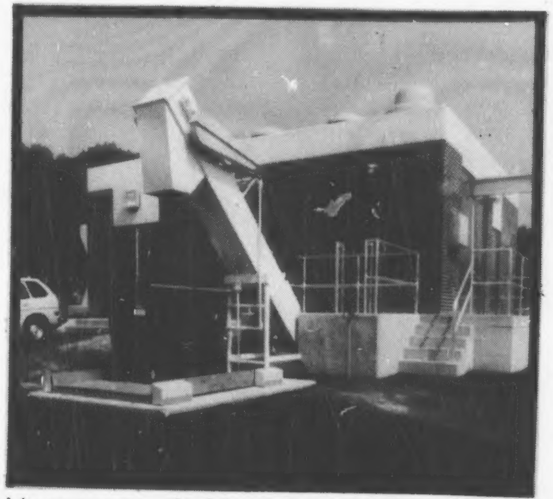
Degritter forms in control building floor



Installation of the Swirl Degritter



The Swirl Degritter in operation



Grit conveyor belt and receiving dumpster

Figure 38. The Swirl Degritter.

## TABLE 13

## LANCASTER SWIRL FACILITY
## CONSTRUCTION COST BREAKDOWN*

| | Work Description | Amount |
|---|---|---|
| | General Construction: | |
| 1. | Mobilization and Job Overhead | $28,000 |
| 2. | Excavation & Demolition | 49,700 |
| 3. | Fencing, Paving, Erosion Control & Landscaping | 17,200 |
| 4. | Concrete, Forms, Reinforcement & Masonry | 103,600 |
| 5. | Prefabricated Swirl Degritter & Swirl Concentrator Parts | 16,000 |
| 6. | Roofing, Painting, Doors, Misc. Hardware & Metal | 60,700 |
| 7. | Plumbing, Piping, Valves, Heating, Ventilation and Misc. Accessories | 107,300 |
| 8. | Discostrainer, Samplers, Pumps, Hoists & Chlorination Equipment | 79,000 |
| 9. | Screw and Belt Conveyors and Grit Scale | 39,700 |
| 10. | Laboratory and Monitoring Equipment | 47,800 |
| 11. | Change Orders | 19,945 |
| | Sub-Total | $ 568,945 |
| | Electrical Construction: | |
| 1. | Excavation and Backfill | 1,837 |
| 2. | Conduit, Wire, Switches, Receptacles | 25,280 |
| 3. | Heaters, Thermostat, Mounting & Connection | 2,644 |
| 4. | Flowmeters and Recorders | 29,151 |
| 5. | Telemetering Alarm System | 5,456 |
| 6. | Generator and Motor Control Center | 26,842 |
| 7. | Control Panel and Misc. Panels | 21,749 |
| 8. | Miscellaneous | 6,752 |
| 9. | Change Orders | 3,680 |
| | Sub-Total | 123,391 |
| | Total Cost | 692,336 |

* 1977 costs (ENR = 3000)

TABLE 14. SUMMARY OF SWIRL FACILITIES CONSTRUCTION COSTS, LANCASTER[a]

| Item | Cost,$ |
|---|---|
| Swirl Concentrator | 168,000 |
| Swirl degritter and grit handling system | 56,000 |
| Control building | 255,000 |
| Instrumentation | 146,000 |
| Disinfection system | 67,000 |
| Total | 692,000 |

a.ENR 3000

### 9.4.1 Operation and Maintenance Costs

The operation and maintenance cost for the first year of operation of the demonstration facilities is estimated at about $58,000. The cost includes operating personnel salaries, supplies, utilities, and a budget for equipment repairs or replacement.

There is a large potential for startup problems and facilities debugging efforts with any newly constructed facility. The annual operation and maintenance budget after the startup period and the demonstration period is expected to be about one-half the first year cost, about $26,000.

# CHAPTER 10

## CONSTRUCTION - WEST ROXBURY PROJECT

### Section 10.1 Foreword

An historical overview of the various phases of construction is presented in section 10.2. Site preparation and inlet structures are described in section 10.3. Swirl fabrication and installation details are provided in section 10.4. Fabrication and installation details for the Helical Bend regulator are given in section 10.5. Influent structure appurtenances are described in section 10.6. Clear water and foul sewer discharge details are provided in section 10.7. Security measures are described in section 10.8. Measurement devices are discussed in section 10.9. Details of the lift station constructed to simulate CSO are discussed in section 10.10.

### Section 10.2 Historical Overview

Grant awards were completed by March, 1978. Preliminary site construction and security measures were initiated during the summer of 1978. A control building was placed on site during this period. Extreme vandalism to the existing security system and control building precluded further site work and fabrication of the units on-site. Instead, EDP fabricated the Swirl and Helical Bend regulators in components in its facility during the fall/winter of 1978. Additional security measures were completed during the spring of 1979 and all site work, piping and installation of the units were accomplished during the summer.

During this period U.S. EPA desired to augment the existing grant to include appurtenances and housing for a third solids seperator device, the Teacup, and to render the site into a more suitable form for viewing by installing a catwalk system. Most of the work at the facility was completed by September, 1979 and preliminary evaluation work began in October. Vandalism continued to plague the facility during the fall/winter/spring of 79-80. Further security measures were taken during this period.

After long delays the Teacup finally arrived from California in April 1980. Upon inspection and close technical review the unit was deemed inappropriate by U.S. EPA and installation/evaluation of Teacup was cancelled.

A bypass foul sewer gating system for the Helical Bend regulator was constructed during the summer of 1980. This modification was added to minimize accumulation in the Helical Bend following storm events.

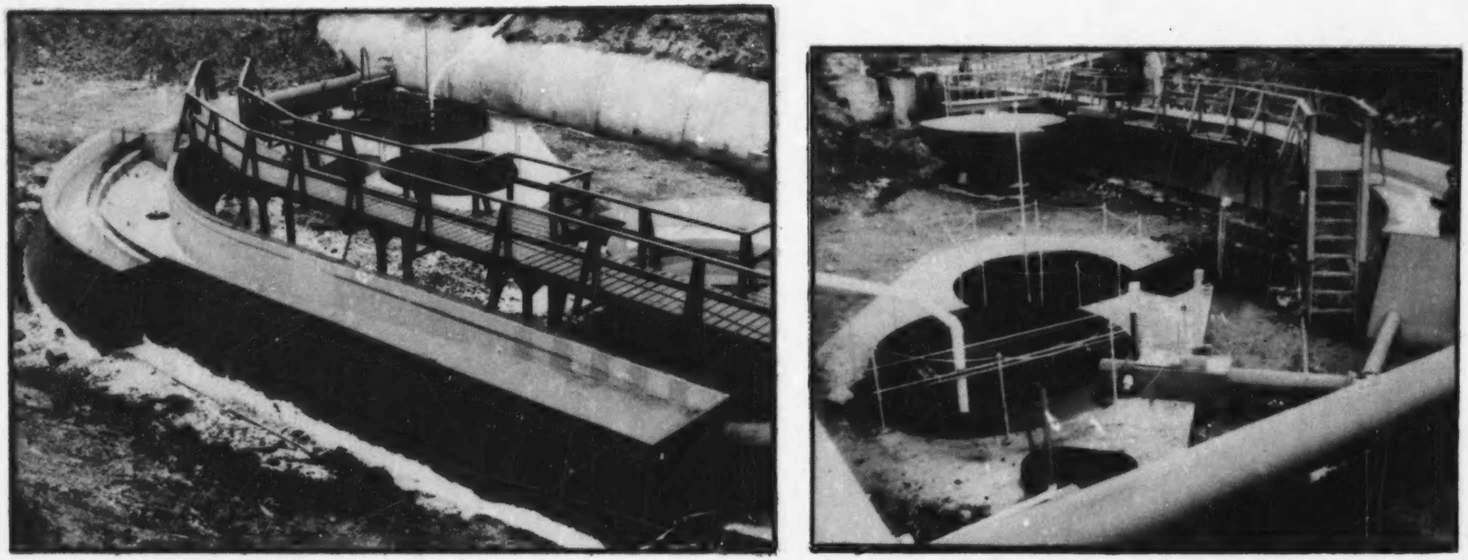
In the fall of 1980 a timber sluice was constructed within the 87 in. (2.2 m) RCP line connecting on-grade the 120 in. (3m) RCP line on New Haven Street to the influent chamber.

Photographs in Figure 39 show the completed facility. For ease in reference a schematic of the facility was depicted in Figure 4 in Chapter 1. Photograph A, Figure 39 (Figure 39-A) was taken from the roof of the control building along the north/south axis. The Helical Bend regulator appears in the lower left hand side of Figure 39-A. The 120 in. (3m) RCP outfall which receives the drainage from the 87 in. (2.2) RCP appears in the upper right hand side of Figure 39-A. The catwalk system shown in the middle of Figure 39-A obscures the Swirl Concentrator from view. Outlines of the foul sewer sump tank, the Teacup housing and the two Palmer-Bowlus flumes can be seen behind the catwalk in Figure 39-A.

The view of the site shown in photograph B, Figure 39 (Figure 39-B) was taken from on top the 120 in. (3m) conduit in a southerly direction (see Figure 4). The Swirl Concentrator appears in the upper left hand side of Figure 39-B. The 24 in. (0.61m) steel Helical Bend clear water discharge line connecting to 120 in. (3m) RCP appears in the lowermost foreground of Figure 39-B. The 8 in. (20.3cm) steel foul sewer discharge from the Helical Bend together with the Palmer-Bowlus Flume housing appears to the right of the catwalk stairway in Figure 39-B. The housing for the Swirl foul sewer Palmer-Bowlus Flume with ultrasonic liquid level recording head is shown just to the left of the catwalk stairway in Figure 39-B. The steel tank housing for the Teacup is just to the of the aforementioned flume in Figure 39-B. The foul sump tank containing a 250 gpm (15.8 l/s) trash sump pump and the 3 in. (7.5cm) pvc discharge appears in front of Teacup housing in Figure 39-B.

### Section 10.3 Site Preparation

The Swirl Helical Bend Regulator/Concentrator treatment complex covers an area of 120 ft x 120 ft (36.6m x 36.6m). The site is located within a natural drainage gully. The westerly side of the site is abutted by an abandoned cinder-filled railroad bed. The access road to the control building within the complex lies on top of the cinder bed. Grade for the site is about 12 ft (3.7m) below natural contour of the gully and at the springline of the 120 in. (3m) drain connecting to the Charles River 1000 ft. (305m) downstream.



A. PHOTO A TAKEN FROM CONTROL BUILDING

B. PHOTO B TAKEN FROM EMBANKMENT
(OPPOSITE DIRECTION AS PHOTO A)

Figure 39. Photographs of completed facilities.

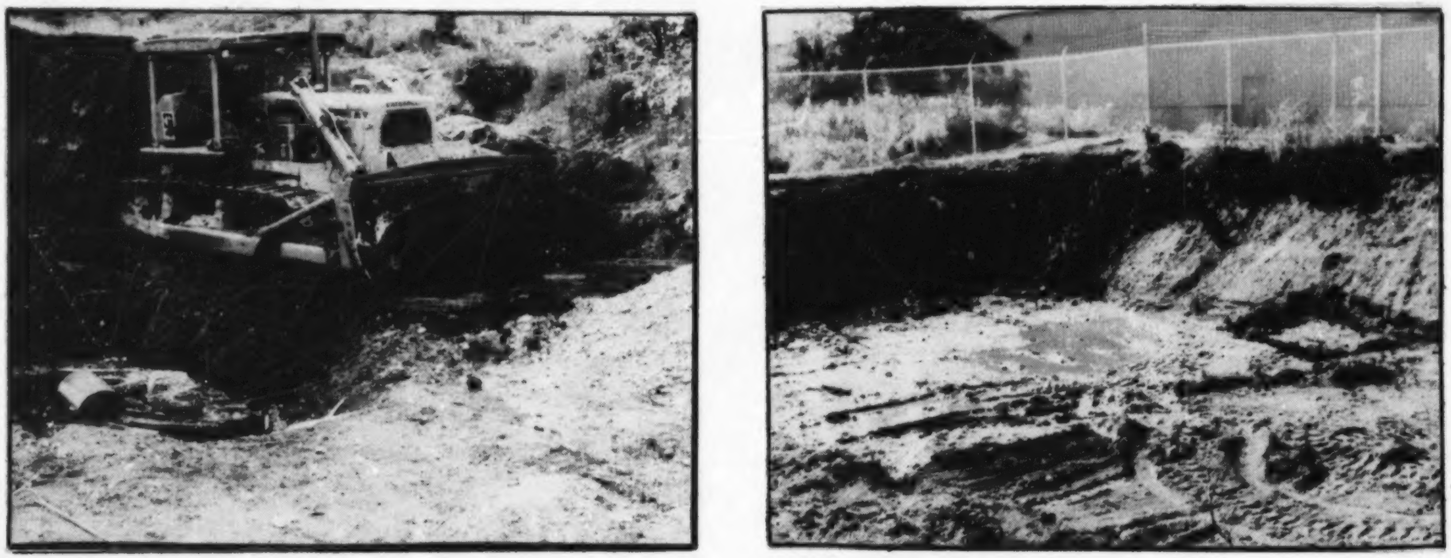
Roughly 4000 cubic yards (3100 cubic meters) of earth required excavation. Fill material was bulldozed (see photograph A, Figure 40) to form two traverse embankments cutting across the gully. The existing 120 in. (3m) drain bordering the east side of the site was laid at a shallow depth and with 5 ft (1.5m) of cover formed a natural embankment. A number of springs were unexpectantly encountered as excavation began. Ground water pooled in the site just at final surface grade (see photograph B, Figure 40). Soil at grade was silt and clay with pockets of sand. All yardwork, slabs, and housing were constructed under severe groundwater conditions as site was a quagmire even during dry weather conditions.

The inlet diversion chamber is a 25 ft (7.6m) x 15 ft (4.6m) reinforced concrete box with side weir inlets. As site excavating began a 3 ft (.91m) ring of high strength reinforced concrete enclosing the conduit (see photograph A, Figure 41) was unexpectantly uncovered. A "window" was cut through the conduit after several weeks of backhoe jack- hammering (see photograph B, Figure 41). The diversion chamber was formed (see photograph A, Figure 42) and 12in. (30.5cm) concrete walls poured.

Two 24 in. (61cm) steel pipe headers from the diversion chamber leading to the two units were installed (see photograph B, Figure 42). Each header had a steel rectangular section (see photograph B, Figure 42) containing two bottom-acting sluice gates (see photograph A, Figure 43). The gates were used to modulate flow into the two treatment devices. A 24 in. (61cm) Palmer-Bowlus flume with a Manning ultrasonic liquid level sensor was installed on each header about 15 ft (4.6m) downstream of the sluice gate chambers to monitor discharge (see photograph B, Figure 43). Strip chart assemblies were maintained in the control building. After the two 24 in. (61cm) Palmer-Bowlus flumes the influent headers to both units reduced to 18 in. (46cm) using steel reducers.

## Section 10.4. Swirl Concentrator Fabrication/Installation

Due to the severe vandalism experienced at the site in the summer of 1978 on-site fabrication of the unit was not attempted. The inner assembly shown in photograph A, Figure 44 was fabricated at EDP's shop. The Swirl steel shed was also shop-fabricated. Photograph B, Figure 44 shows the Swirl shell being lowered into position by a crane at the demonstration site. The influent transition section and the primary/secondary gutters appear at the bottom of the steel tank in photograph B, Figure 44. The 24 in. (61cm) clear water downshaft was then field welded and influent baffle placed (see photograph A, Figure 45. The inner assembly was then placed, leveled and field-welded (see photograph B, Figure 45). Photograph A, Figure 46 shows a top

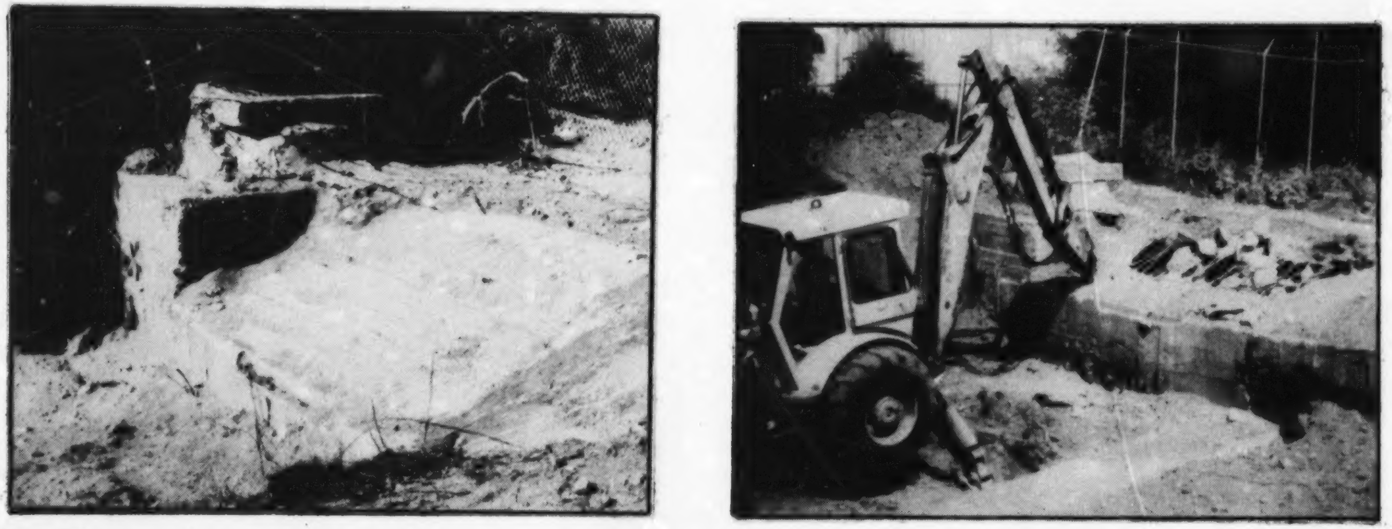


A. INITIAL CUT

B. CUT ABOUT SIX FEET ABOVE FINISHED SURFACE GRADE

Reproduced from best available copy.

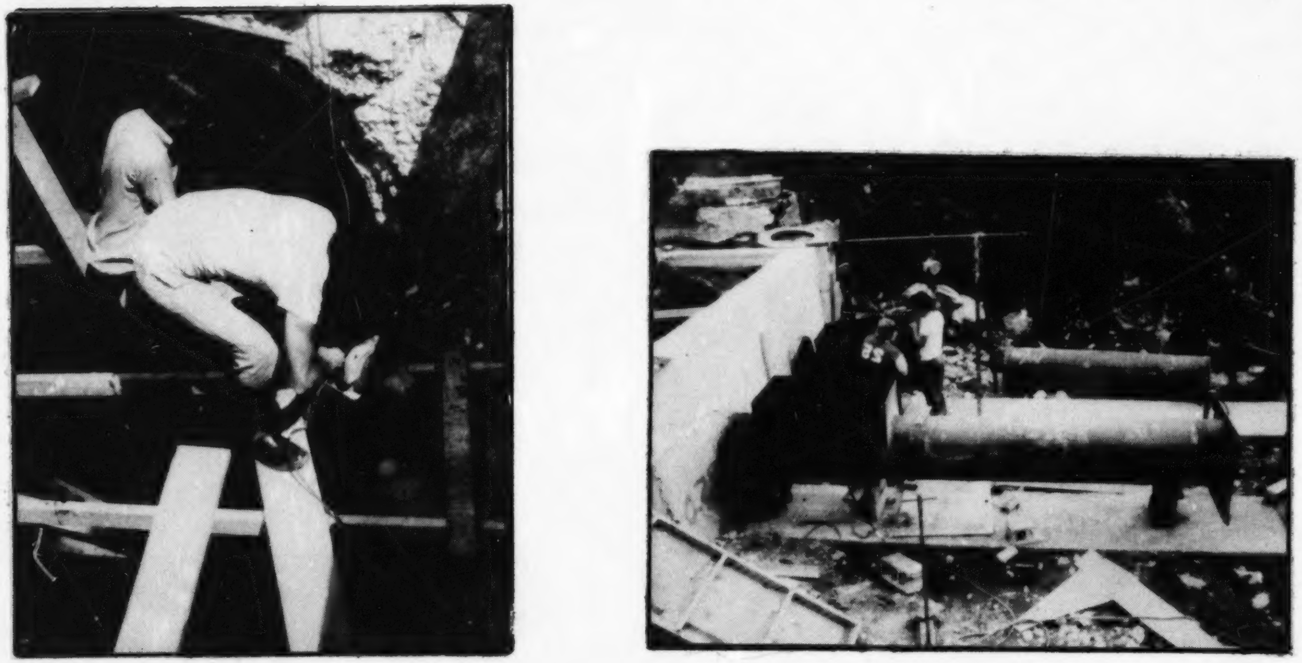
Figure 40. Photographs of site excavation.



A. EXPOSED EXISTING 87IN. (RCP)
W/CONCRETE ENCASEMENT

B. CONCRETE DEMOLITION

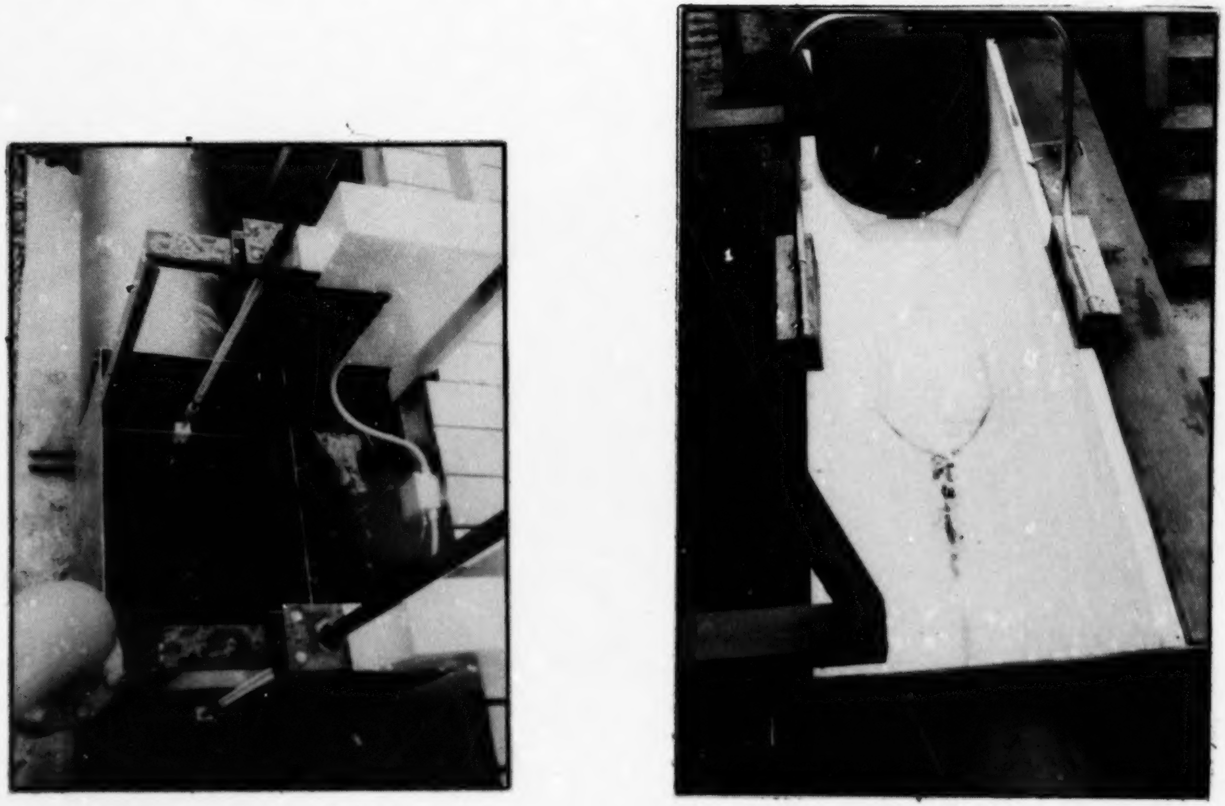
Figure 41. Photographs of Influent Diversion Chamber concrete demolition. 1 in = 2.54 cm



A. FORMING INFLUENT SIDE WALL SPILLWAY

B. INFLUENT PIPING MANIFOLDS

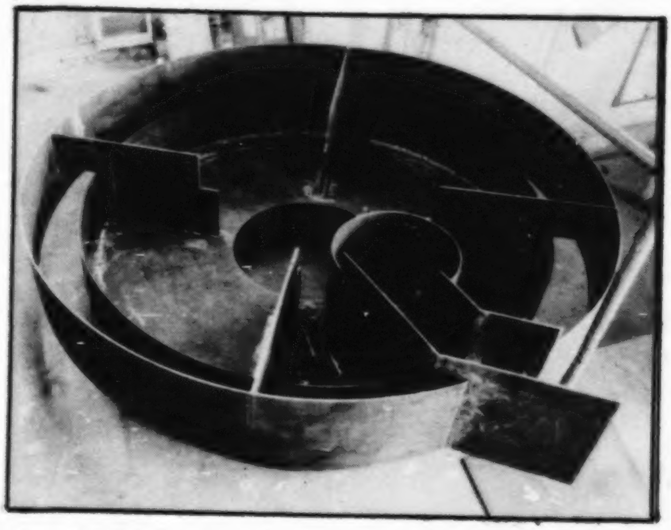
Figure 42. Photographs of Influent Diversion Chamber - sidewall construction details.



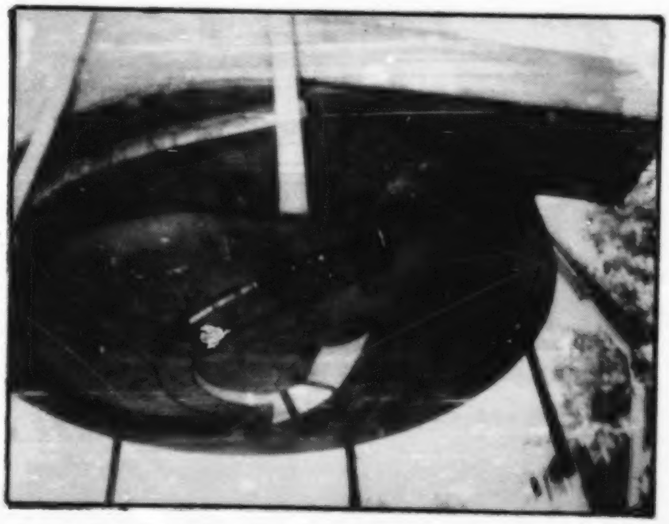
A. TOP VIEW, BOTTOM-ACTING SLUICE
GATES, SWIRL INFLUENT

B. TOP VIEW, HELICAL BEND
PALMER-BOWLUS FLUME (ULTRASONIC)

Figure 43. Photographs of Influent Gates & Flumes.

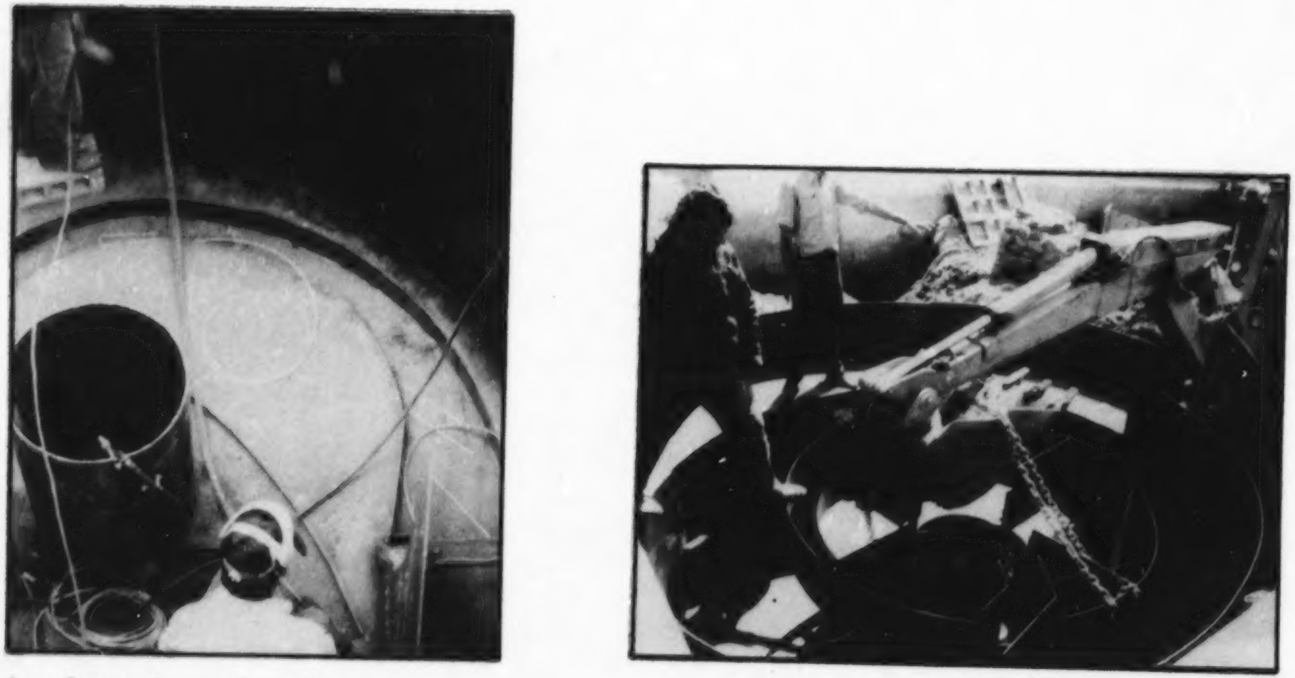


A. INNER ASSEMBLY



B. SWIRL STEEL SHED (UNDERSIDE)

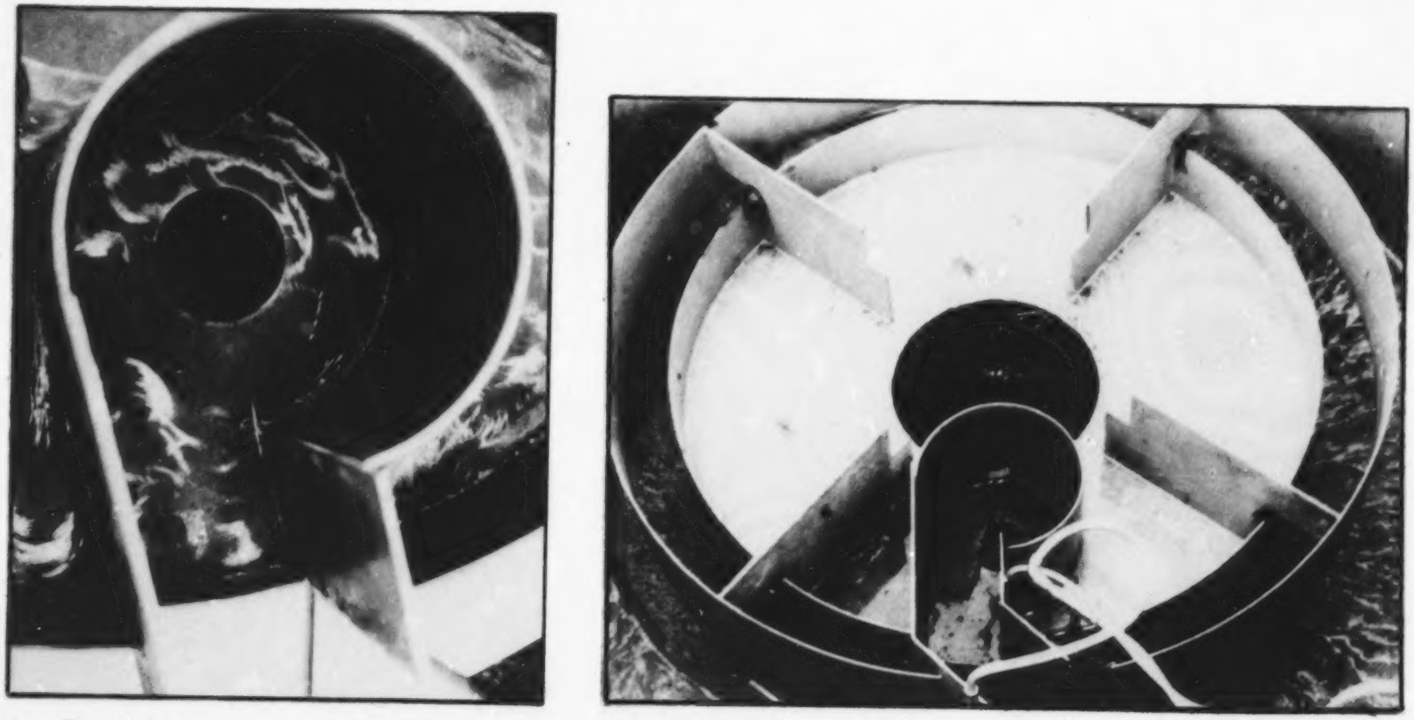
Figure 44. Photographs of shop-fabricated Swirl Solids Separator components, W. Roxbury.



A. SWIRL STEEL SHED INTERIOR (CLEARWATER SHAFT-LHS)

B. LOWERING PRE-FABBED INNER ASSEMBLY

Figure 45. Photographs of field assembly - Swirl Solids Separator, W. Roxbury.



A. Top View of Floatable Trap

B. Swirl at End of Storm

Figure 46. Photographs of completed Swirl Solids Separator, W. Roxbury.

view of the floatables trap. Note that floatables are restrained between the side of the tank and the scum ring and then are swept into the trap by the swirl motion within the tank. Localized vortex motion draws and stores the floatables within the trap below the weir plate/collar. Photograph B, Figure 46 shows a top view of the Swirl immediately after a storm event.

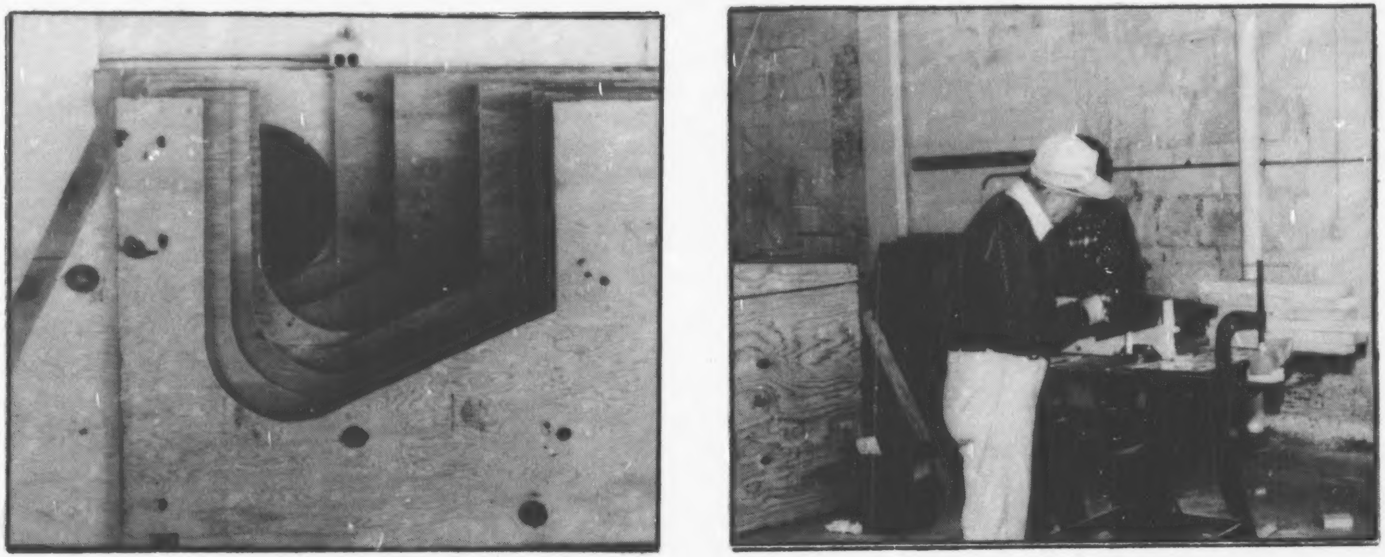
## Section 10.5. Helical Bend Fabrication/Installition

Photograph A, Figure 47 shows a stack of cut plywood sheets depicting the geometric progression of the Helical Bend's cross-sectional ribs. Two ft (.61 m) wooden 2 in. (5 cm) x 4 in. (10 cm) studs were cut and beveled at each end (see Photograph B, Figure 47). A computer program was written to describe in three dimensions the various bevel cuts for roughly 1200 stud segments. Different beveled cuts were necessary since the Helical Bend cross section flared in both plan and profile. The logistics of these cuts were accomplished only after a great deal of difficulty.

Photographs A and B, Figure 48 depict typical construction details for attaching wooden studs to the plywood ribs. Each stud was attached 8 in. (20.3 cm) on centers to the plywood sheets with wood glue and several wood screws. Studs were staggered on each side of the rib as shown in both photographs in Figure 48. Triangular plywood sections were attached to the outside of each rib adding overall stability. Photograph A, Figure 49 depicts the triangular stabilizers.

Photograph B, Figure 49 was taken from the influent end and depicts the transitional and straight sections of the Helical Bend. Photograph A, Figure 50 was taken from the centerline of the straight section within the Helical Bend and depicts the flared cross section of the transition section. Photograph 3, Figure 50 was taken in reverse direction and shows the treatment section. The clearwater weir and backside of the clearwater overflow trough are depicted in the background of Photograph B, Figure 50 while the wall nearest the foul sewer trough appears in the right foreground.

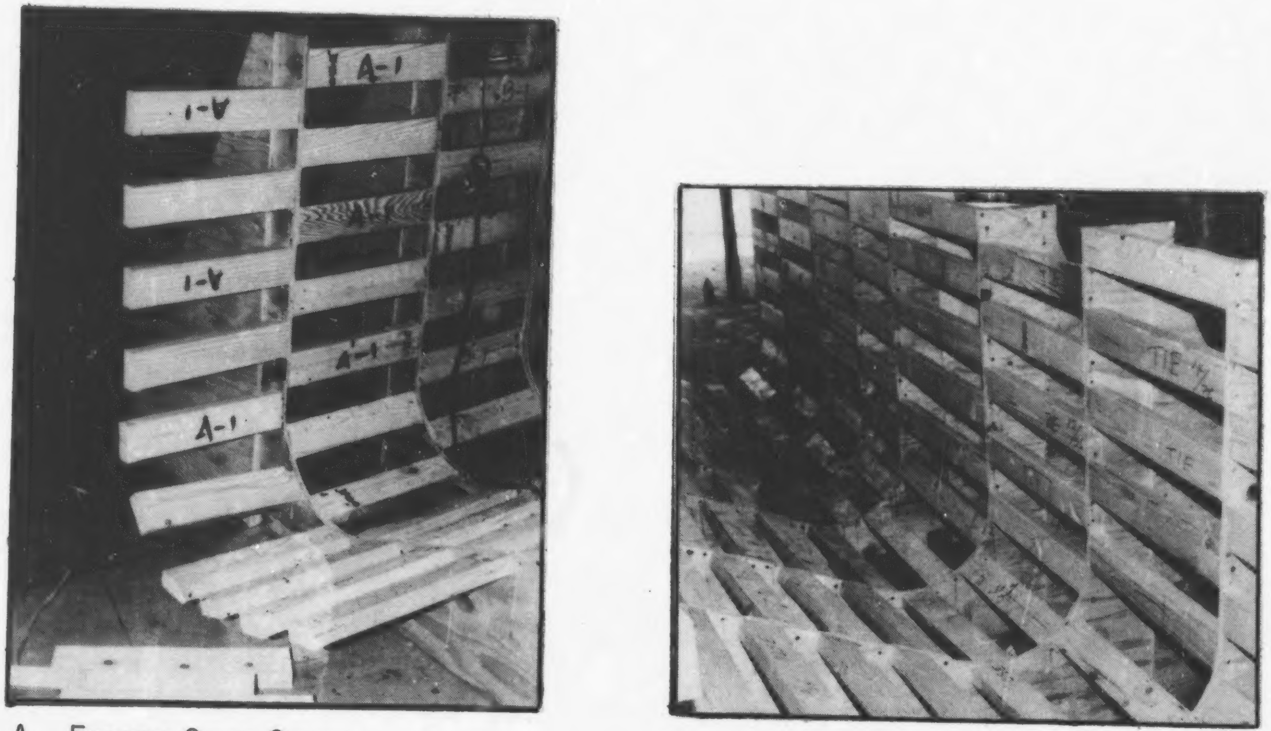
The plywood ribbed structure was then sheeted with 0.040 in. (1mm) 6061-T6 aluminum sheeting. Photograph A, Figure 51 shows partial cover of aluminum sheeting on the clearwater weir while photograph B,Figure 51 shows sheeting on the foul sewer trough. Photograph A, Figure 52 was taken from the effluent end of the Helical Bend regulator showing the curved foul sewer section in the foreground and the clearwater weir in



A. STACKED PLYWOOD RIBS

B. BEVELING WOODEN STUDS

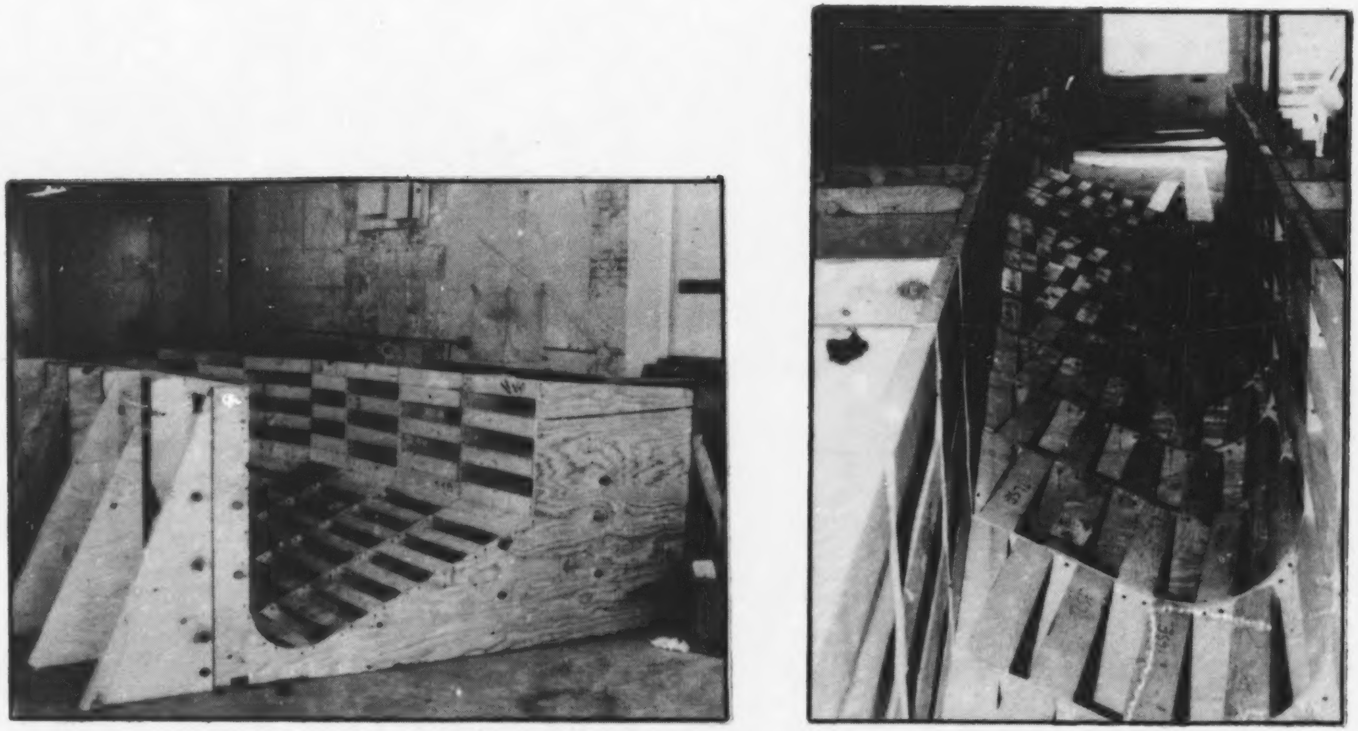
Figure 47. Photographs of Helical Bend wood fabrication.


A-1
A-1
A-1
A-1
A-1
TIE

A. FORMING CROSS-SECTION

B.

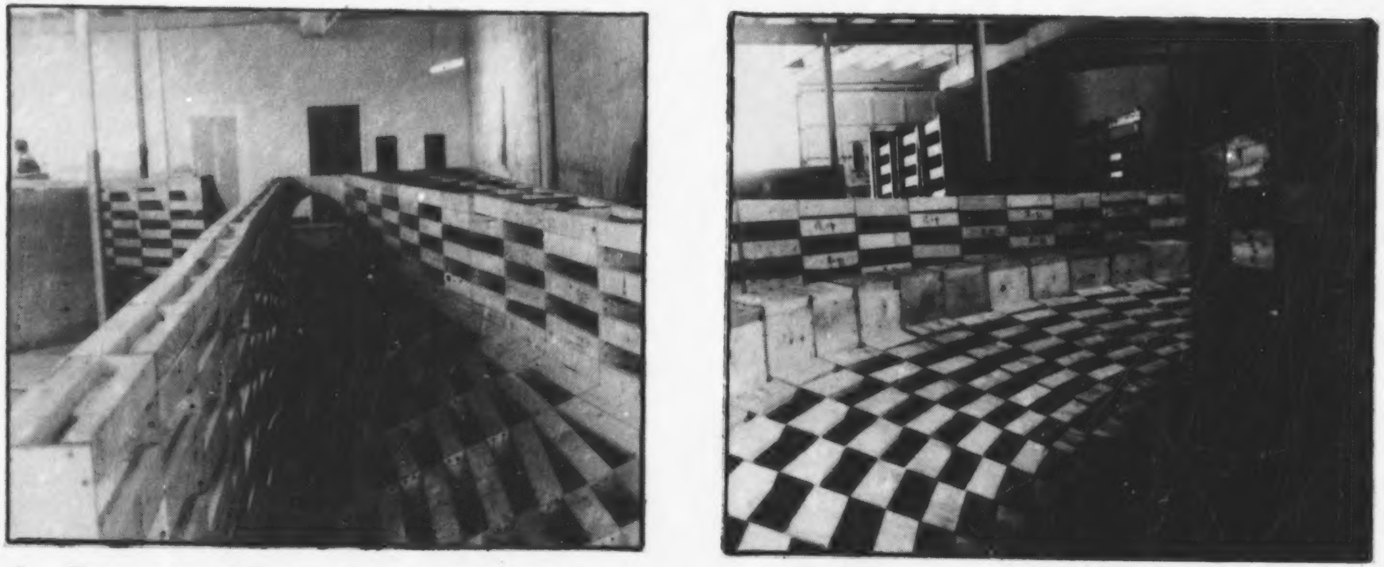
Figure 48. Photographs of Helical Bend Regulator, wooden fabrication details.



A. STRAIGHT SECTION

B. TRANSITION & STRAIGHT SECTION
(PHOTO TAKEN FROM INFLUENT END)

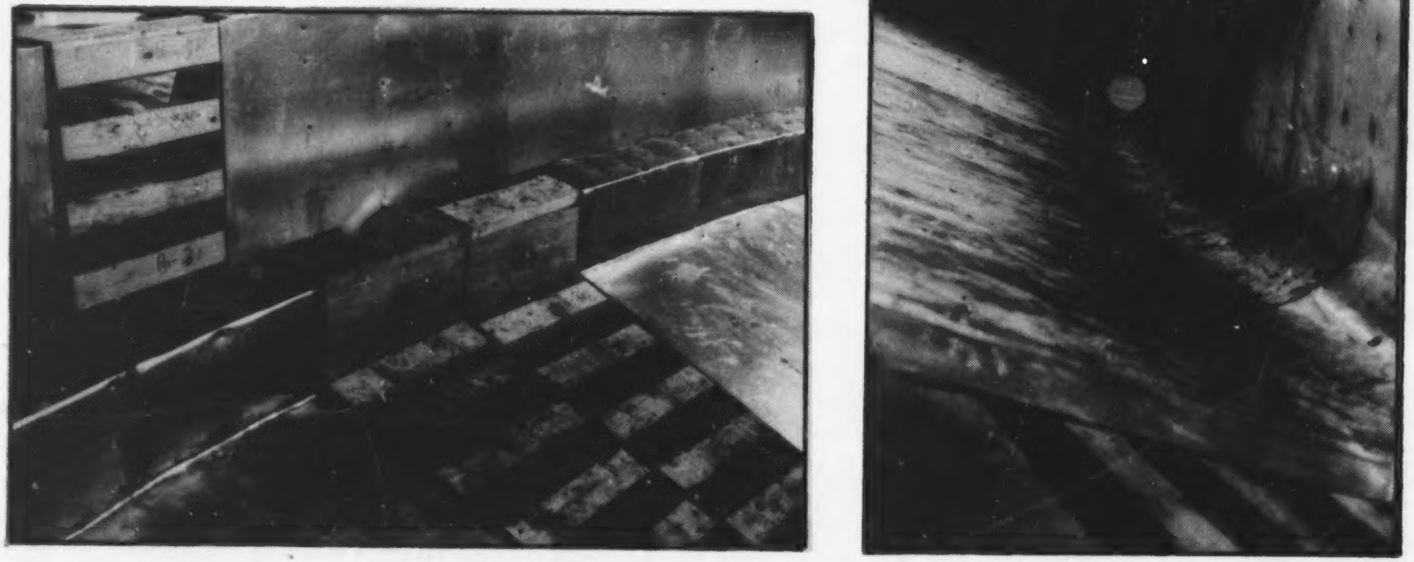
Figure 49. Photographs of Helical Bend wooden shell (in progress).



A. Transition Section (photo taken in straight section)

B. Treatment Section (clear water weir in backround)

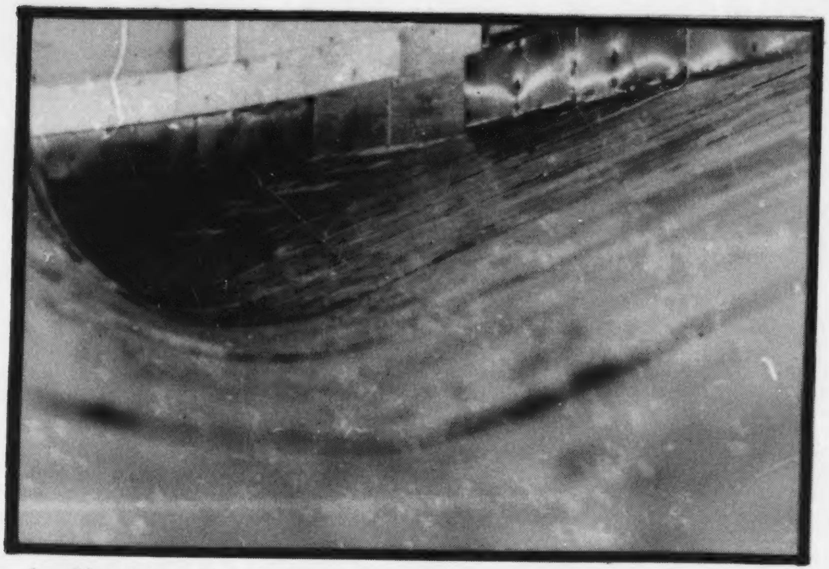
Figure 50. Photographs of Helical Bend wooden shell (completed).



A. PARTIAL SHEETING - OVERFLOW WEIR/TREATMENT SECTION

B. PARTIAL SHEETING - FOUL SEWER OUTLET

Figure 51. Photographs of Helical Bend aluminum sheeting interior.



A. Aluminum Sheeting - Foul Sewer Channel

B. Aluminum Sheeting - Interior

Figure 52. Photographs of Helical Bend aluminum sheeting interior.

the upper background. As the sheeting was nearing completion, Photograph B, Figure 52 was taken from the influent end and depicts the clearwater weir in the background.

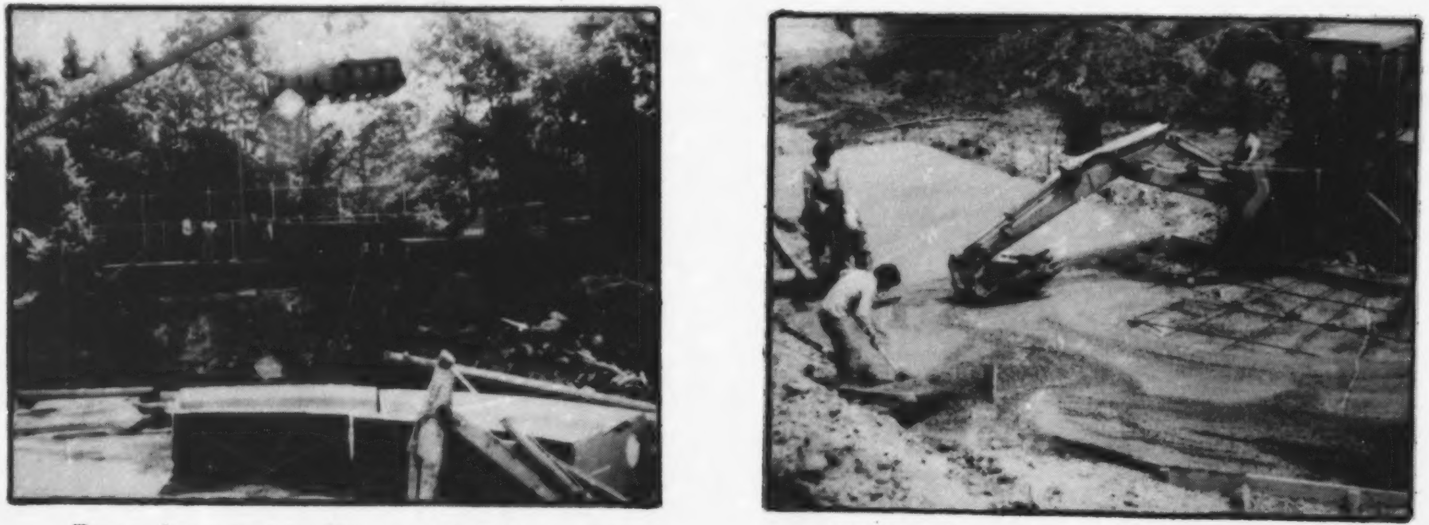
A 12 in. (30.5 cm) reinforced concrete slab was poured at a 2% grade as shown in photograph A, Figure 53. The four sections of the Helical Bend were transported from EDP's shop facility to the site and lowered onto the concrete slab by crane (see photograph B, Figure 53). The regulator was fabricated into four structurally intact sections (approximately 15 ft (4.6 m) in length). Plywood ribs were attached by angle iron onto two welded steel channel pieces to form each section of the regulator. Each section had been fabricated as a structural member capable of withstanding erection stresses.

The external surfaces of the Helical Bend were primed (see photograph A, Figure 54) and the inner surface sanded (see photograph B, Figure 54) before two coats of epoxy were applied. Protective plywood sheeting was then fastened to the outer triangular stabilizer (as shown in photograph A, Figure 39) and then curved stainless steel scum and clearwater weir baffles were attached (as can be seen in photograph A, Figure 39).

## Section 10.6. Influent Structure Appurtenances

As previously mentioned in Chapter 8, discharge from the catchment area is through a 30 in. (76.2 cm) RCP on New Haven Street into a short segment of 87 in. (221 cm) RCP approximately 250 ft (76.2 m) in length. The inlet chamber to the demonstration site is along the 87 in. (221 cm) pipe section.

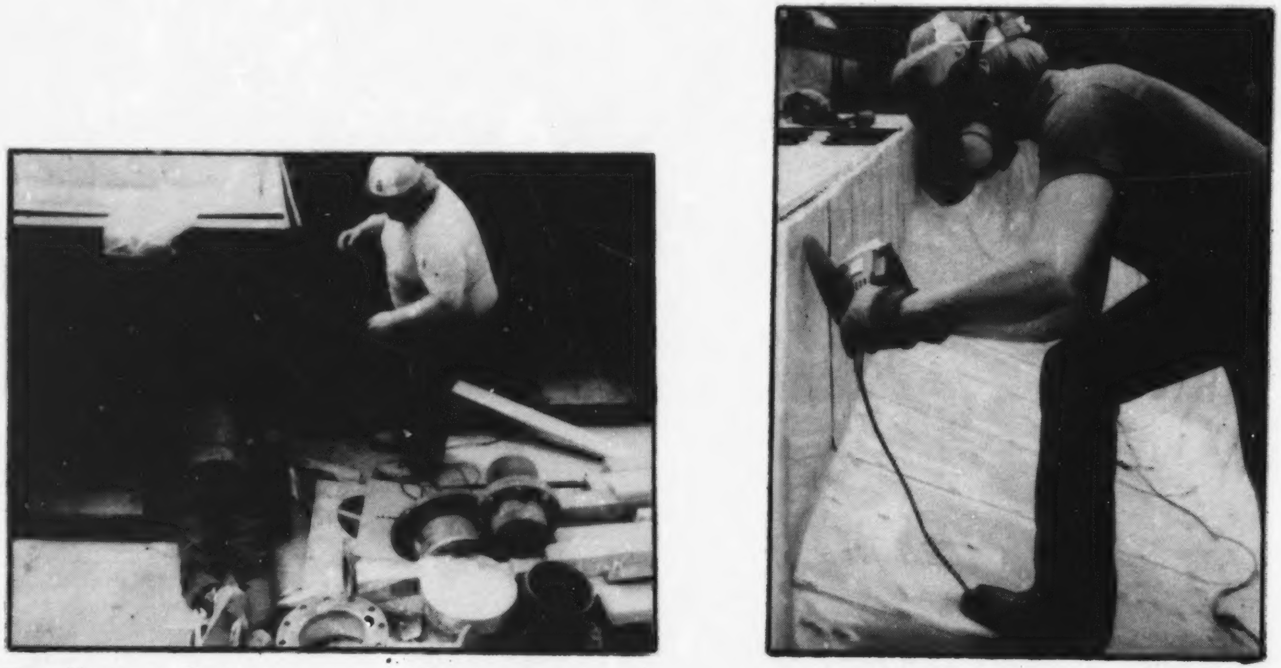
The original plan for diverting flow in the 87 in. (221 cm) influent storm drain to the facility consisted of 2 in. x 6 in. (5 cm x 15 cm) creosoted wooden stop-logs placed in slots constructed in the influent chamber box forming an adjustable weir to control sideway discharge into the inlet chamber box. After the facility was completed in September, 1979 and during the initial debugging period, an EDP field crew on September 30 placed stop-logs at a nominal setting as to create discharge into the units just before a storm event. The intensity of the storm was severe, creating nearly full pipe discharge in the 87 in. (221 cm) line. The field crew attempted to manually remove several planks as to relieve the backwater effects. The hydrostatic pressure was such that the planks had to be removed with a chain-fall involving EDP personnel climbing into the 87 in. (221 cm) line at great personal hazard. To remedy this hazard, stop-logs



Field Assembly of Helical Bend Sections

Helical Bend Concrete Pad

Figure 53. Photographs of Helical Bend on-site installation.



A. HELICAL BEND EXTERIOR - OIL PRIMED COATED

B. HELICAL BEND INTERIOR - ALUMINUM SHEETING PREPARED FOR EPOXY COATING

Figure 54. Photographs of final surface preparation for Helical Bend.

were attached in sections to form a segmented bottom-opening sluice gate operated by a motorized assembly located on top of the diversion chamber.

As mentioned above a baffle system was constructed to raise the water level up to the mid-point on the 87 in. (221 cm) conduit allowing for side discharge into the treatment facility. An upward-sloped wooden ramp was also constructed to move particles if entrained in the 87 in. (221 cm) line up into the units. It turned out that during low intensity/long duration rainfall events the ramp was inadequate in transporting settleable solids into the units. To rectify this problem, a wooden flume in the 87 in. (221 cm) conduit connecting the end of the 30 in. (76.2 cm) RCP line on New Haven Street to the 2 inlets at the treatment facility was built in fall, 1980. This wooden sluice is approximately 185 ft. (57 m) long. The flumes rectangular cross section was later revamped into a triangular section in spring, 1981. The revised section permitted average velocities exceeding 3 ft/sec (.91 m/s) for all depths of flow.

## Section10.7 Effluent Appurtenances

The clear water discharge from the Swirl is below site grade and is a 24 in. (61 cm) steel pipe connected to the 120 in. (3 m) storm drain about 1.5 ft (.46 m) about invert. The Helical Bend clear water discharge is similar in dimension and appears on the left side of photograph B, Figure 39. The 8 in. (20.3 cm) steel foul sewer is again below grade extends roughly 25 ft (7.6 m) on a flat slope and connects to a flanged 8 in. x 10 in. (20.3 cm x 25.4 cm) 90 degree Hydro-Brake. The 10 in. (20.3 cm) foul sewer line continues to a 10 in. (25.4 cm) Palmer-Bowlus flume with a Manning ultrasonic liquid level sensing head. The Helical Bend foul sewer discharge is again an 8 in. (20.3 cm) steel line and is above grade (see photograph B, Figure 39). The 8 in. x 10 in. (20.3 cm x 25.4 cm) right angle flanged Hydro-Brake for this line can also be seen in the photograph on Figure 55.

Both foul sewer lines discharge into the foul discharge tank 10.5 ft (3.2 m) in diameter and 6 ft (1.8 m) in depth. This tank appears in the foreground in photograph A, Figure 56. The foul sewer sump trash pump and piping assembly appears in Photograph B, Figure 56.

As mentioned above the foul sewer outlet on the Helical Bend is regulated by a right angle Hydro-Brake, permitting discharge of about 0.2 cfs (5.7 l/sec) implying discharge velocity of 0.7 fps (21.4 cm/sec). The over-sized line was installed to prevent debris clogging and the Hydro-Brake was

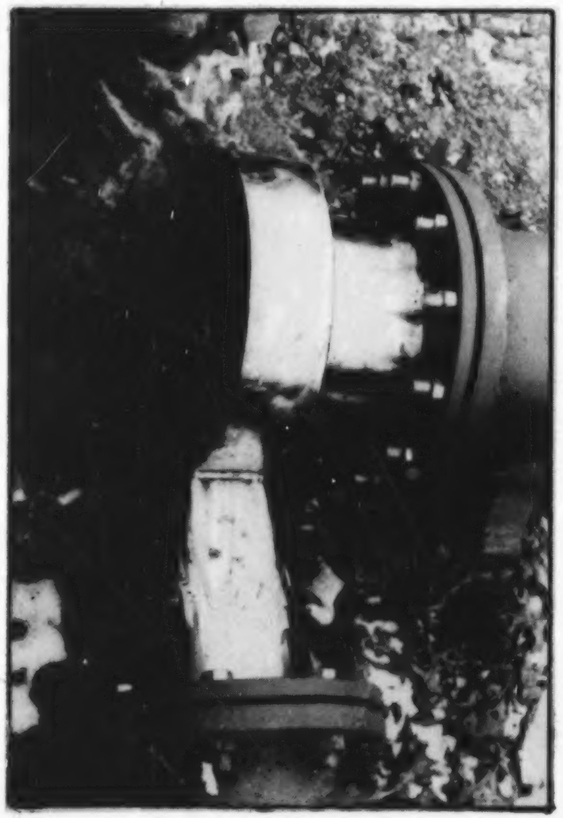
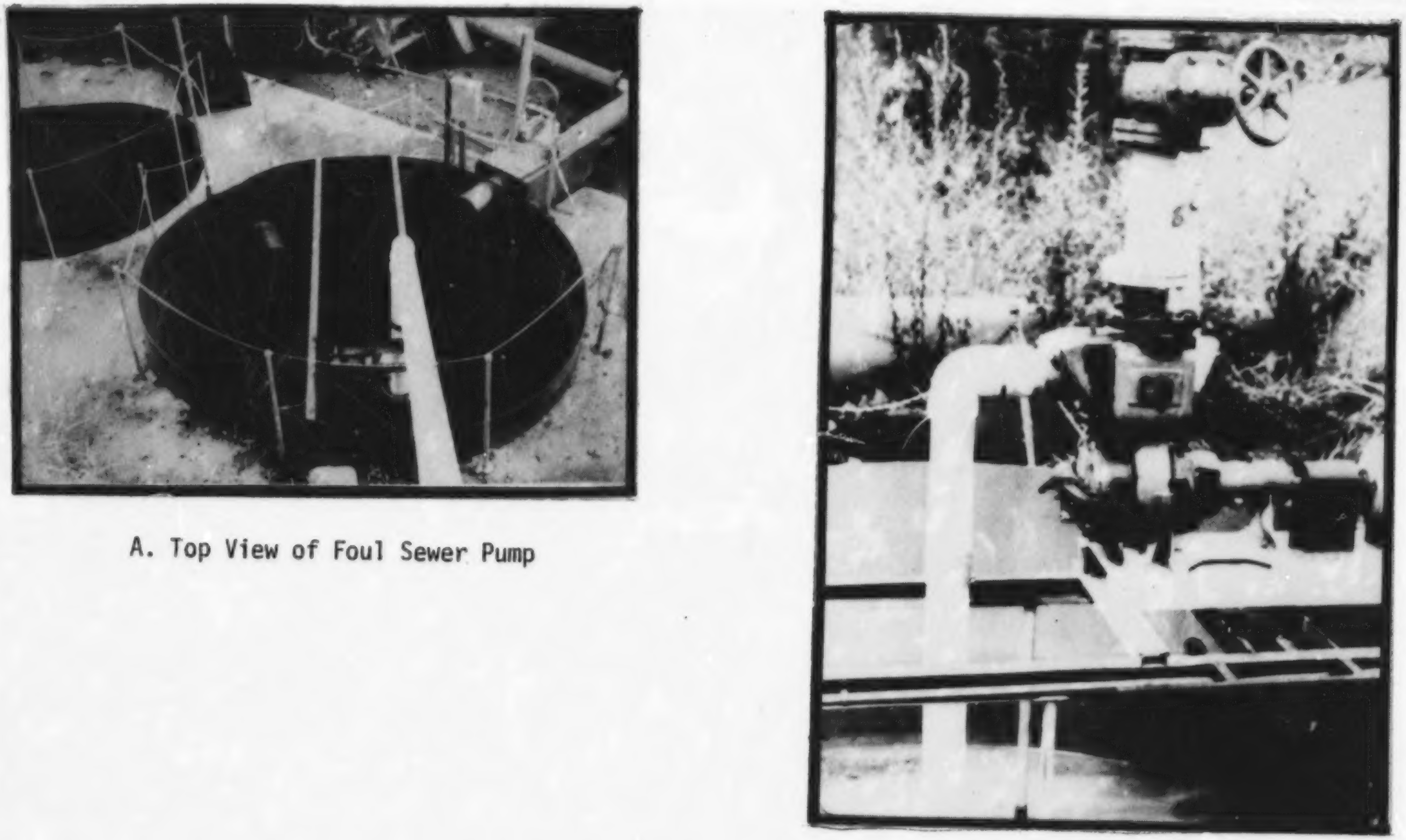


Figure 55. Photograph of 8in X 10in 90° flanged Hydro-Brake (Helical Bend Foul Sewer). 1in = 2.54 cm.



A. Top View of Foul Sewer Pump

B. Trash Pump

Figure 56. Photographs of Foul Sewer Sump.

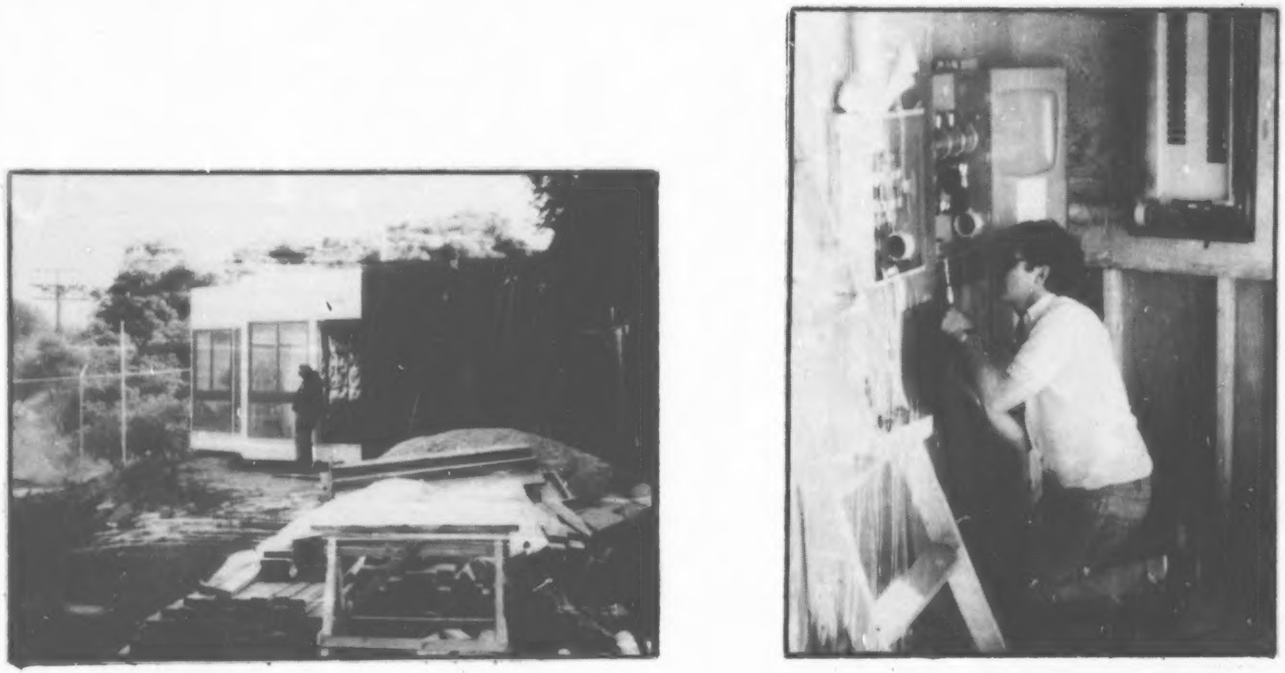
included to limit underflow to about 3% of design flow, 6 cfs (170 l/sec). Substantial deposition of settleable and floatable materials resulted during the early phases of the evaluation programs, in the lower effluent end of the Helical Bend treatment section during rainstorms because of the low exit velocities and the off-set of the 8 in. (23.2 cm) x 10 in. (25.4 cm) Hydro-Brake. This situation requires that the unit be hand-cleaned after an event. To remedy this situation, an 8 in. (23.2 cm) bypass line with a motorized valve was constructed with the inlet at the same elevation of the existing foul sewer outlet and the outlet connected to the foul sump tank. The 8 in. (23.2 cm) motorized valve provided a quick flush of the remaining volume within the unit. The motorized valve was activated from the control building.

## Section 10.8. Security Measures

The demonstration site was initially surrounded by an 8 ft (2.4 m) high chain-link cyclone fence topped with three strands of barbed wire. A 20 ft x 20 ft (6.1 m x 6.1 m) pre-fabbed modular control building was moved in and erected within the fenced perimeter. This building had been formerly used in a water pollution control R&D project in Boston. (see photograph A, Figure 57). The project site immediately became the target of a tremendous amount of vandalism including crushed barbed wire supports, defacing and burning of the control building, smashing of existing explosion-proof lighting fixtures, and destruction of all existing control board circuitry and panels. The building was twice burnt and electrical control panels replaced by EDP (see photograph B, Figure 57).

Additional security measures included: a second 12 ft (3.8m) high non-climbing security fence which was topped with razor-blade ribbon barbed wire (see photograph A, Figure 58), the area was defoliated, overhead lights were installed, on-site guard service was used during sensitive construction times, and sensing alarm systems installed in the control building and at two locations on the catwalk sending signals both to a nearby guard service and to turn on audio alarms at the site. (Photograph B, Figure 58 shows the catwalk under construction).

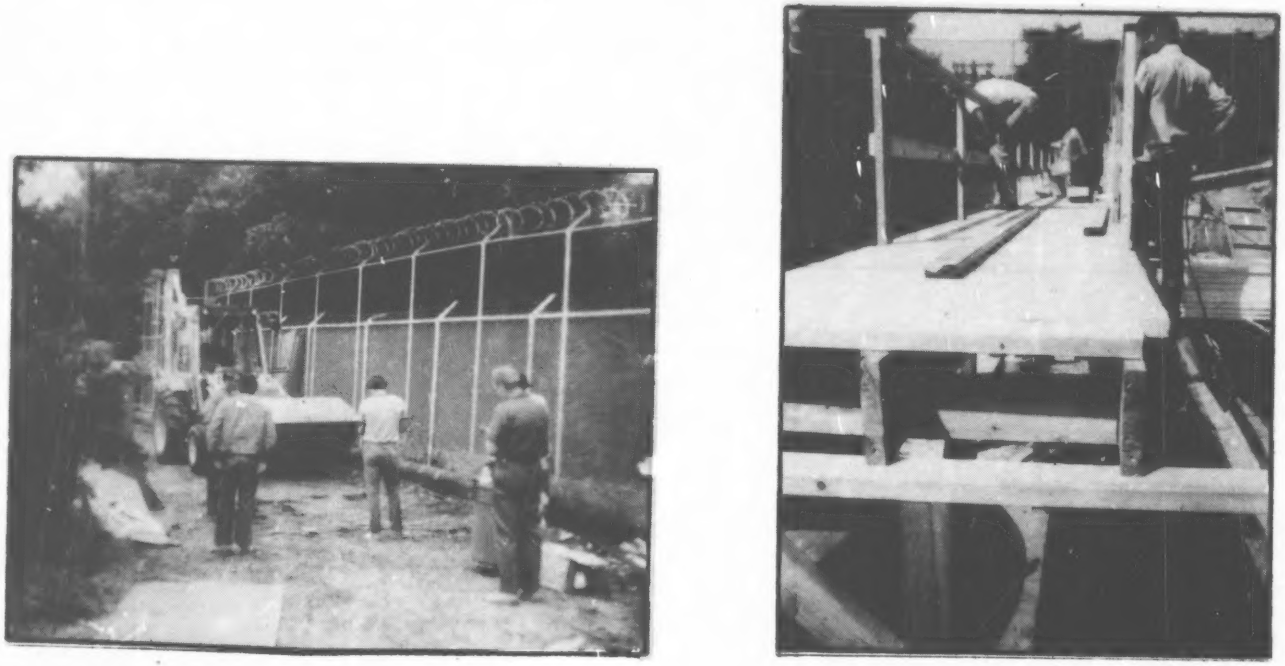
The security fence gate was vulnerable to vehicles traveling at high speed on the access road. Twice, vehicles travelling at high speeds crashed and completely demolished both sets of gates. EDP fabricated and replaced both pairs of gates for the two security fences and finally constructed a steel "crash" fence located 15 ft (4.6 m) in front of the outer fence constructed of heavy steel "I" beams with side braces mounted on 6 in. (15 cm) heavy wall steel pipes, filled with concrete and embedded in substantial



A. CONTROL BUILDING (SECURITY GUARD NEXT TO BUILDING)

B. RESTORING VANDALIZED ELECTRICAL CONTROL PANELS

Figure 57. Photographs of control building, W. Roxbury.



A. SECURITY FENCES

B. CATWALK CONSTRUCTION

Figure 58. Photographs of sitework.

concrete footings. Major vandalism was stopped but rock missles thrown from outside the area perimeter constantly demolished control building windows.

## Section 10.9. Measurement Devices

Monitoring of the performance of the two control devices required two types of measurements, both flow and quality, at several points along each regulating device. Flow was monitored at the influent, clear water effluent and foul sewer discharge utilizing Palmer-Bowlus flumes and ultrasonic meters. Quality measurements were taken at the drain outlet box (common input to both treatment devices), clear water discharges and effluent streams by use of both flow compositing and discrete automatic sampling devices. The actual readouts for the flow monitors and controls for the sampling devices were housed in the building itself. Further details are provided in Chapter 11.

## Section 10.10. Simulated Combined Sewer Lift Station

Part of the Swirl and Helical Bend evaluation program entailed testing the efficiency of the two units using as influent simulated combined sewer overflows. As shown on Figure 4, Chapter 1 a lift station was installed to pump up to 2 cfs (56.6 l/s) of sanitary sewage from the 27 in. (69 cm) VCP trunk sewer (adjacent to the 120 in. (305 cm) RCP storm drain) during rainfall events and mix this waste with incoming storm drainage from the catchment area. Dry weather flow in the 27 in. (69 cm) line was gaged for several months in 1978. Average flow equalled 0.5 cfs (14.2 l/s). The tributary sanitary system was severly impacted by clearwater inflow and flows quickly rose typically to 9 cfs (255 l/s) during several monitored rainfall events.

U.S. EPA provided a used 6 in. (15 cm) pump capable of discharging 2 cfs (56.6 l/s). The pump was installed in summer, 1979. The first time it was turned on the pump seals burst. EDP disassembled the pump, repaired the seals and replaced the pump during 1980. The pump was again turned on during an evaluation event during spring, 1980 (4/4/80) and again the seals burst and the impellars were damaged. Since pump components had to be hand-carried down the embankment in pieces and then assemblied in an extremely space-constrained area, it was deemed infeasible to again repair this pump. This portion of the evaluation project was not performed.

# CHAPTER 11

# Evaluation Methods

## 11.1 Foreword

This chapter details the methods used in monitoring the treatment units for both projects. An overview of the instrumentation methods for the Lancaster facility is presented in section 11.2. Sampling schemes at Lancaster are discussed in section 11.2.1. Problems with the initial 1978-1979 Huth monitoring program are presented in section 11.2.2. Specialized samplers which were fabricated and installed in Lancaster by EDP Technologies, Inc. are described in section 11.2.3. Problems with the flow monitoring devices in Lancaster and calibration efforts are reviewed in section 11.2.4.

Section 11.3 includes an instrumentation overview of the West Roxbury facility. Sampling schemes are discussed including related problems and solutions and flow monitoring devices are reviewed. Section 11.4 details the design, and implementation of the motorized bi-directional rotating settling column, along with a description of the settling column used on-site at Lancaster. Section 11.5 reviews all the analytical procedures used in the analysis. Section 11.6 describes various calulation procedures for noting performance of the two demonstration facilities. Section 11.7 describes various methods for presenting settling column results.

## 11.2 Evaluation Program Overview - Lancaster Swirl Project

### Initial EDP Review and Project Startup

On July 19, 1979 EDP was invited to visit the Lancaster Swirl facility to assess the numerous and persistent monitoring program difficulties. The site visit began with a review of sampling difficulties encountered to date. Inspection of the existing sampling system yielded numerous system faults and recommendations as outlined in section 11.2.1. Based on this visit, EDP was contracted in July, 1980 to oversee the remainder of the evaluation program.

During the early stages of EDP's involvement with the project, the resident engineer provided EDP with written records documenting project activities starting 7/25/78 through 1979. These records included daily log books, storm event rain records and operational records depicting flow rates and pollutant concentrations.

Review of this material provided the needed insight for proper program formulation for future activities. The daily logs were studied to determine typical operational procedures, equipment reliability, repairs and changes and the actual adequacy of the reports themselves.

A listing of rain events was made including the necessary information to determine typical frequency, duration and intensity of storm events. Combined with the daily reports and sampled event data, estimates as to the types of storms worthy of evaluation were determined. Strip-chart records for numerous storm events were reviewed to estimate typical flow response to rain events and determine the quality of flow data. Based on this review equipment repairs were recommended and optimal level sensor adjustments were determined.

As of July 1980 the evaluation project had been inoperative for many months. During this time several physical adjustments to the facility layout were recommended by EDP and some were implemented. The evaluation program was re-activated at this time and with the exception of some equipment malfunctions, a good data base was collected covering four storm events during the fall of 1980.

During the winter of 1980-81 the evaluation program was ceased pending repair of influent flow monitoring and sampling equipment. Evaluation of pollutant loadings and removals had been limited only to concentration considerations due to questionable flow data, and the inability of the existing automatic sampling scheme to define solids build-up in the unit and final flush characteristics. To remedy this problem special samplers were installed, debugged and finally rendered operational to monitor the influent waste streams for both the Swirl Concentrator and Swirl Degritter. Extensive efforts were also performed to calibrate the existing flow monitoring equipment with little success.

## Facility Operation

In the final analysis, the adequacy of the evaluation of the Lancaster Swirl Concentrator as a pollution control device depended upon it being representative of a typical swirl installation. A careful review of the Lancaster facility operation demonstrated several problems which directly affect the suitability of the Lancaster unit as a representative installation.

First, the facility layout has normal dry weather flow passing through the unit. Storm event monitoring is initiated when the depth within the swirl is 18 in. (46 cm). Calculations show that at the time the swirl level reaches 18 in. (46 cm), flow through the Degritter bypass pipe is 8 cfs (226 l/s). Considering the normal dry weather flow of 3 cfs (85 l/s) much of the initial storm flow will have passed through the swirl before wet weather operation is initiated. During this time no samples are collected, thereby missing a portion of the "first flush". At this time, the Swirl is filling at a much slower rate than would occur if the maximum bypass rate was closer to the actual dry weather flow rate. Two corrective measures were considered. First a flow-limiting device could be inserted in the Degritter bypass line. Second, the wet weather activation level could be reduced below 18 in.(46 cm).The problem with each of either of these approaches is the tendency to clog the Degritter with organic materials. Either of the above measures would cause occasional unit activation and valve-opening to the Degritter during abnormally high dry weather flow and the high organic solids content of this flow would cause continual problems with the degritter. This problem was not resolved during the evaluation program.

Second, the storm event monitoring is terminated when the Swirl level returns to 18 in. (46 cm) at which point the Degritter bypass is opened. With the Lancaster setup the flow then also bypassed the foul effluent flow meter and sampling port. Evaluation of the Swirl at West Roxbury has indicated that much of the solids matter is not continually removed from the unit but accumulates until the end and passes as a "final flush". This implies that at the Lancaster facility much of the solids may be discharged from the unit after sampling ends.

Third, the Lancaster facility had a continuence of equipment malfunctions. One influent flow meter was not operating and a backup meter periodically malfunctioned. In addition, various level sensors and recorders were of questionable accuracy since it was discovered that dimensions used in calibrating many of the strip chart recorders were unknown. In some cases actual settings were unreasonable. A low setting on the emergency weir level meter created off-scale flow readings and the diversion chamber settings greatly limited resolution.

## Field Trips

In addition to preliminary site evaluation, EDP personnel visited the Lancaster Swirl site in summer, 1980 to discuss the scope of the evaluation program after a complete review of the facility history and operation and an inspection of all equipment had been made. After four storm events had occurred in the fall

1980 and the data assessed, additional meetings were held to discuss the further recommendations and required changes. Due to the continual problems with flow monitoring equipment on-site visits were deemed necessary.

During these visits the following actions were accomplished:

1) Accuracy and calibration check of Swirl ultrasonic liquid level meter.

2) Installed instrumentation necessary to obtain a second Swirl level record to provide an expanded chart span at the height of the Swirl weir.

3) Reset spans of various other level sensors to optimize strip chart records. This work included expanding the emergency overflow weir record span to prevent additional "off-chart" events and reducing the diversion chamber span to yield more reasonable resolution. Communications with Huth Engineering and City of Lancaster indicatedthat for many of the earlier strip- charts the referencing dimensions were unknown. These were determined as necessary.

4) Performed hydraulic tests upon the inoperative 475 Doppler influent flow meter (accompanied by the Leeds and Northrup representatives).The meter proved unrepairable in the field and was removed for factory inspection and repair.

5) Performed hydralics tests upon the malfunctioning Mapco ultrasonic meter.

6) Measured and recorded level of Swirl clear overflow weir. Attempts to level weir by adjusting turnbuckle supports resulted in a level weir at the four points of support contact, but non-level conditions in mid-sectionsdueto plate warpage. Finallevel measurements were taken at numerous points to assist in using the circular weir equation for flow measurements. However,it was assumed that continual plate warpage due to differential thermal heating would render these values useless in a short time.

7) Inspected the 36 in. (91.4 cm) influent pipe including the area selected for installation of the dye injection system and the area of the ultrasonic transducer ports. Debris was found in the transducer ports leading to the recommendation that a cleaning and inspection routine be developed.

In a parallel effort described in section 11.2.3 EDP Technologies, Inc. fabricated, shop-tested and installed two new sampling devices on the influent conduits to the Swirl Concentrator and Swirl Degritter. These devices were designed to take a liquid sample from the entire cross-sectional pipe area over a short instant of time. The purpose of the devices was to ensure representative sampling of flow/solids stratification characteristics, that is, bedload suspended load and wash load.

### 11.2.1 Details of Sampling Locations at Lancaster

The initial sampling program at Lancaster consisted of a series of Manning 6000 samplers located in the laboratory area on the second floor of the facility. Operation of these units required drawing the samples from various distances within the basement area ranging one to two stories below the units. In the first year of Huth evaluation (1978-1979) this measurment system proved to be inadequate in providing representative grit components in the samples. EDP recommended two series of adjustments.

The first set of adjustments involved re-positioning the Manning samplers and revising the intake systems to take maximal advantage of existing equipment. The second set of adjustments involved installation of new state-of-the-art sampling equipment by EDP Technologies, Inc. Two sampling schemes were used during the EDP (1980-1981) performance evaluation. First, the Manning samplers were located to provide the best possible samples under the given circumstances. These positions are indicated in Figure 59. Swirl influent was sampled in the 36 in. (91.4 cm) line just prior to discharge into the Swirl Concentrator. The Manning sampler was located in an enclosed structure at ground level and coupled to an intake consisting of three copper tubes placed horizontally across the 36 in. pipe. Holes drilled in the tubes were sized to provide optimum intake velocity, good cross sectional representation and allow catchment of maximum diameter particles. The Swirl clear overflow samples were collected using a Manning sampler located on the catwalk. A copper intake tube was positioned horizontally along the inner side of the overflow weir.

Swirl foul flow was sampled via a port located tangentially to the invert of the swirl degritter inlet transition section. A probe was inserted through this port and positioned to sample the center pipe flow. An intake similar to that on the Swirl clear weir was used for degritter overflow samples. Both the Swirl foul flow and Degritter clear flow samplers were Manning units located on the basement floor.

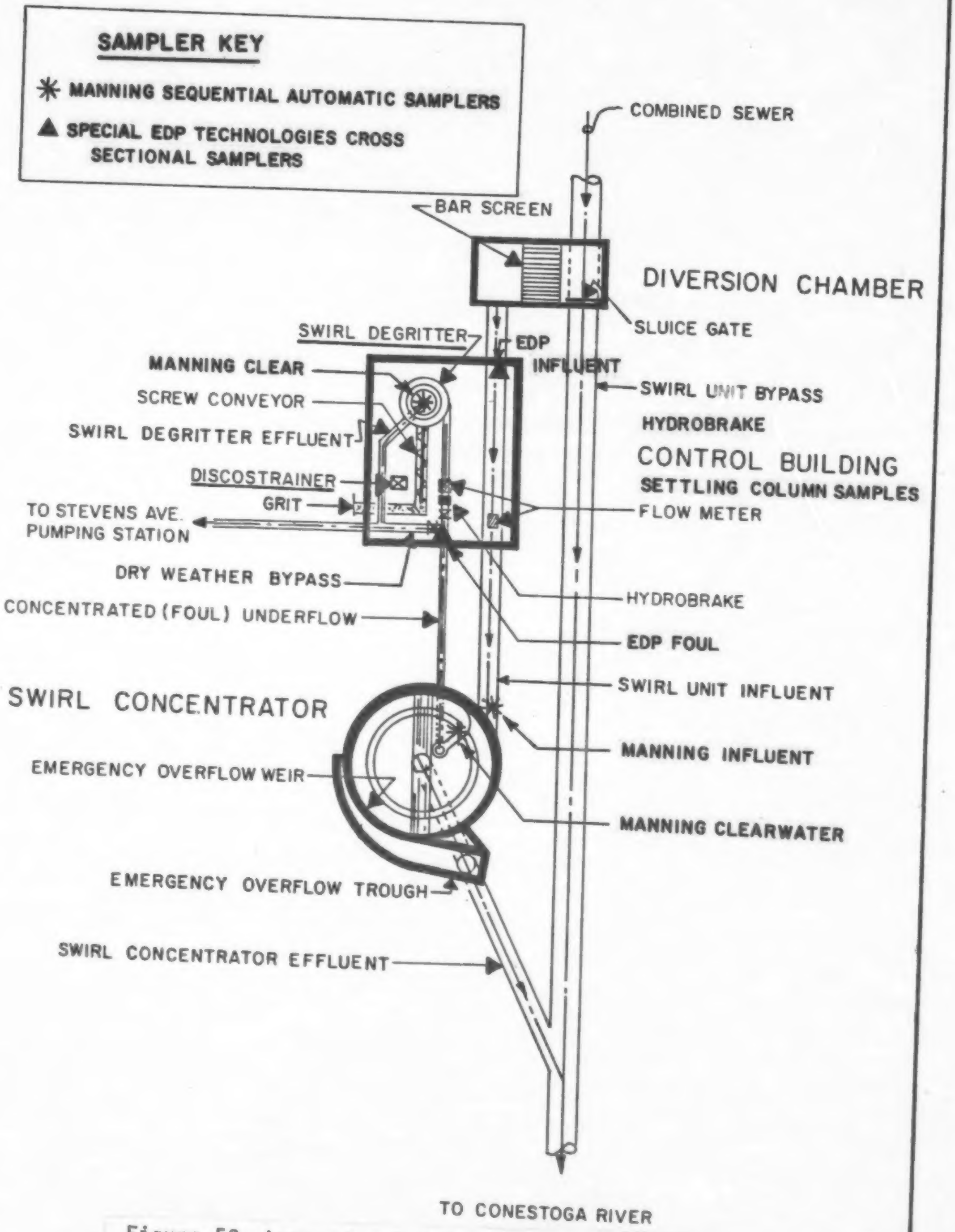

SAMPLER KEY
✳ MANNING SEQUENTIAL AUTOMATIC SAMPLERS
▲ SPECIAL EDP TECHNOLOGIES CROSS SECTIONAL SAMPLERS
COMBINED SEWER
BAR SCREEN
DIVERSION CHAMBER
SLUICE GATE
SWIRL DEGRITTER
EDP INFLUENT
MANNING CLEAR
SCREW CONVEYOR
SWIRL DEGRITTER EFFLUENT
SWIRL UNIT BYPASS
HYDROBRAKE
CONTROL BUILDING
SETTLING COLUMN SAMPLES
DISCOSTRAINER
GRIT
TO STEVENS AVE. PUMPING STATION
FLOW METER
DRY WEATHER BYPASS
HYDROBRAKE
CONCENTRATED (FOUL) UNDERFLOW
EDP FOUL
SWIRL UNIT INFLUENT
SWIRL CONCENTRATOR
MANNING INFLUENT
EMERGENCY OVERFLOW WEIR
MANNING CLEARWATER
EMERGENCY OVERFLOW TROUGH
SWIRL CONCENTRATOR EFFLUENT
TO CONESTOGA RIVER

Figure 59. Lancaster Swirl Project sampling locations.

The second sampling scheme utilized the cross-sectional samplers installed by EDP Technologies, Inc. The 36 in. (91.4 cm) EDP Technologies influent sampler was located on-line within the building roughly one-fifth the distance from the diversion chamber to the Swirl unit. The new EDP Swirl foul sewer sampler was installed on the 12 in. (30.5 cm) line after the dry weather bypass connection and before the flow meter an Hydro-Brake. Operation of this unit required dismantling the Manning sampler previously used for foul flow sampling. All other samplers used during the first phase were utilized thereafter. Influent sample collection using both the Manning and EDP units allowed for comparison of the effectiveness of sampling.

Settling column samples were collected manually from both the Swirl Concentrator and Swirl Degritter. Clear samples were collected at the center of the overflow pipe in each unit. Influent samples for the Swirl were taken from various points in the influent channel. Degritter influent samples were taken from a 2 in. (5 cm) valve at the invert of the 12 in. (30.5 cm) influent pipe to the degritter, just downstream of the Hydro-Brake.

### Section 11.2.2. Initial Monitoring Problems

In 1979 EDP was invited to visit the Lancaster Swirl facility to assist in upgrading the facility monitoring devices. The site visit began with a review of sampling difficulties encountered to date at the swirl facility.

Flow was measured at the influents to the Swirl Concentrator and the Swirl Degritter via various pressurized pipe monitoring devices. Quality measurements are taken at four locations including influent and clear water effluent on the Swirl Concentrator and influent and clarified effluent from the Swirl Degritter.

Inspection of the existing sampling system yielded numerous system faults. The piping was far too complicated and lengthy to deliver "representative" samples to the intakers of the Manning 6000 samplers. Sediment deposition was an obvious problem. More important was the fact that some of the sample streams were subjected to passage through centrifugal pumps prior to actual sampling. Solids passing through these pumps were subjected to maseration.

The Swirl Degritter influent loop as constructed, drew from a tap-in point after flow measurement and discharged into the city main sewer line, effectively forming a bypass of all subsequent operations. Due to the large size of the lines and pumps involved a significant portion of the influent to the Swirl Degritter would not reach the unit. Performance measurements taken, that is, total amount of grit produced, were biased.

Flow measurement to the Swirl Degritter was accomplished by means of a magnetic flow meter on the influent line. The Hydro-Brake used to control the Degritter flow was located upstream of the magnetic flow meter. Since the Hydro-Brake by design induces a radial flow pattern from its discharge, and since magnetic flowmeters are designed for reasonably laminar flow, it was unlikely that the flow readings measured were correct.

The influent flow to the Swirl Concentrator is gaged by two primary flow meters on the 36 in. (91.4 cm) influent line. The original Mapco unit has a problem of "zeroing" on high flow regimes, undoubtedly due to excessive influent flow velocities transposing the sonic waves downstream of the receiver causing a zero response. As a consequence an additional Leeds and Northrup Doppler unit was installed and it malfunctioned.

### 11.2.3 Specialized EDP Automatic Influent Sampling Devices

Implementation of the first set of adjustments recommended by EDP was not predicted to completely alleviate the problems with non-representative sampling. To obtain better sampling EDP Technologies, Inc. fabricated and shop-tested two new sampling devices to be placed on the influent conduits to the swirl and swirl degritter. The purpose of the devices was to ensure representative sampling of flow/solids stratification characteristics, that is, bedload, suspended load and wash load. The devices were complete flanged assemblies.

#### Operation of Slide Sampling Device

The slide sampling devices constructed for installation on both the 36 in. (91.4 cm) Swirl Concentrator and 12 in. (30.5 cm) Swirl Degritter influent lines took a cross-sectional slice of the influent discharge during a sampling sequence. The sampler consists of three main parts: the containment shell, the slide cell and the sample bottle cassette. Figure 60 shows the details of the 36 in. (91.4 cm) influent sampler used for the influent to the Swirl Concentrator. The sampler for the Swirl Degritter was fabricated in exactly the same fashion.

#### Containment Shell

The containment shell consists of a rectangular box approximately three times as long as the given pipe diameter and slightly larger than the pipe diameter in height. Welded to the

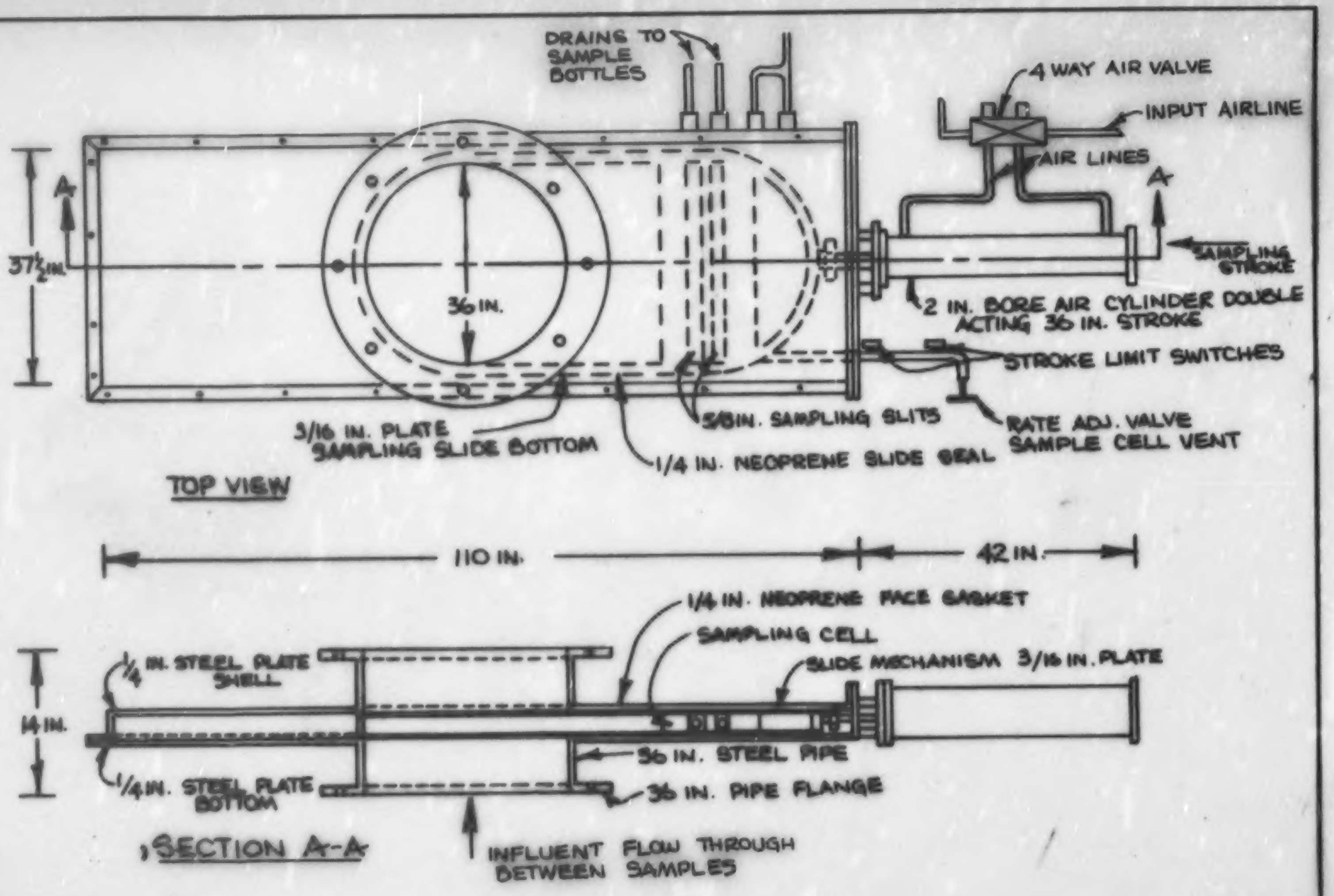

DRAINS TO SAMPLE BOTTLES
4 WAY AIR VALVE
INPUT AIRLINE
AIR LINES
A
A
SAMPLING STROKE
37½ IN.
36 IN.
2 IN. BORE AIR CYLINDER DOUBLE ACTING 36 IN. STROKE
STROKE LIMIT SWITCHES
RATE ADJ. VALVE SAMPLE CELL VENT
5/8 IN. SAMPLING SLITS
3/16 IN. PLATE SAMPLING SLIDE BOTTOM
1/4 IN. NEOPRENE SLIDE SEAL
TOP VIEW
110 IN.
42 IN.
1/4 IN. NEOPRENE FACE GASKET
SAMPLING CELL
SLIDE MECHANISM 3/16 IN. PLATE
1/4 IN. STEEL PLATE SHELL
14 IN.
1/4 IN. STEEL PLATE BOTTOM
36 IN. STEEL PIPE
36 IN. PIPE FLANGE
SECTION A-A
INFLUENT FLOW THROUGH BETWEEN SAMPLES

Figure 60. Diagram of 36 in. Influent Sampling Device (typical).

rectangular containment box are a pair of pipe nipples and flanges allowing for bolt-in installation of the unit.

### Sampling Cell

The sampling slide cell is a rectangular box that fits inside of the containment shell sealed on four sides by a neoprene face seal. Two rings of the pipe are welded into the slide as shown on Figure 60. The innermost ring is open on both sides allowing for influent flow-through, with no restriction during intervals between samplings. The outermost ring or sampling cell is enclosed on both sides with the exception of a slit extending vertically on the upstream or influent face one sixth the width of the pipe diameter. The sampling cell is moved inward and outward by means of an air-cylinder, as shown. Samples collected in the sampling cell will drain to the appropriate sample bottle by means of a 1-in. (2.54 cm) pvc pipe line.

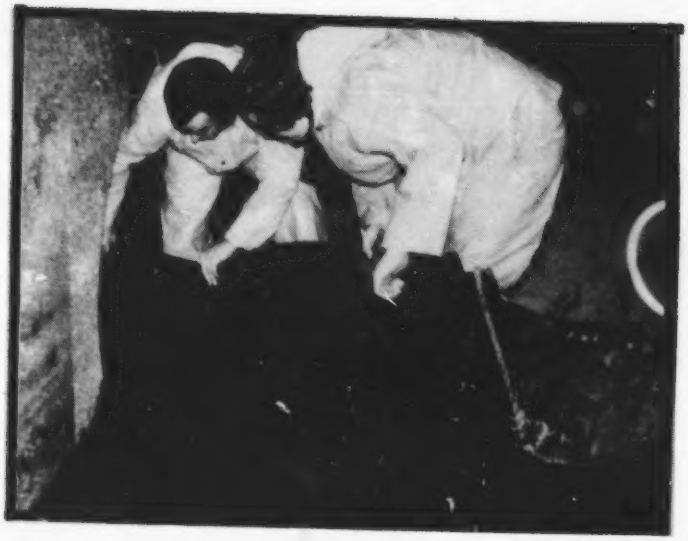
### Sample Bottle Cassette

The sample bottle cassette will hold a total of 24 1-l sample bottles, stacked on two rotary tiers. Each sampling cycle will cause the rotary cassette to be indexed to the next bottle position. Drainage to the sample bottles is by gravity through the 1-inch (2.54 cm) sample line.

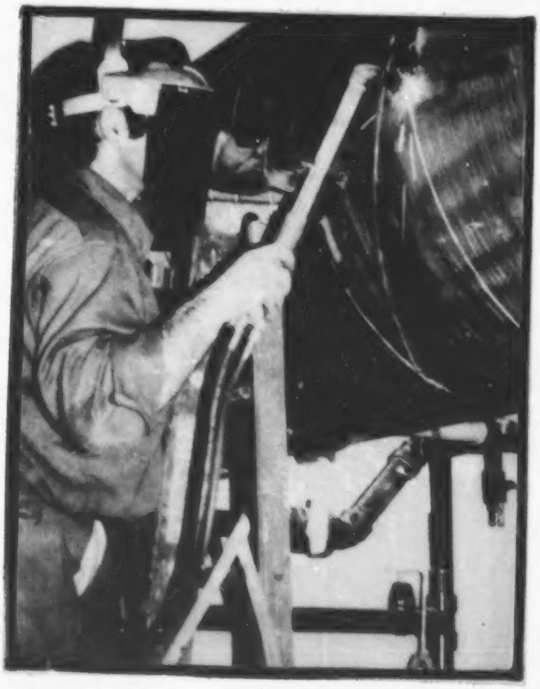
Photographs of installation are shown in Figures 61 through 64. EDP Technologies, Inc. personnel first removed the bar screen in the diversion chamber and inserted an inflatible dam in the Swirl influent line (see photograph A, Figure 61) since there was no means for shutting flow to the Swirl. The 36 in. (91.4 cm) influent passed through the basement of the control building near ceiling level. Photograph B, Figure 61 shows the cutting operation on the 36 in. (91.4 cm) influent line. Insert from page 9.

Photograph A, Figure 62 illustrates the 36 in. (91.4 cm) EDP Technologies sampler suspended over the Swirl Degritter as it was lowered through an opening in the laboratory floor to the basement floor. The containment shell, flanged ends and air cylinder are included. The Swirl Degritter is 8 ft (2.4 m) in diameter indicating the magnitude of the sampler size. Photographs in Figure 63 depict various views of the 36 in. (91.4 cm) sampler being installed.

PhotographA, Figure 64 illustrates the completed sampler assembly for the 12 in. (30.5 cm) pipe with the two flanged connections. Attached to the containment shell is the control panel as seen on the right of the photo. Controls allow selection of sampling mode and delay intervals and include indicator lights



A. Inserting Inflatible Dam in Swirl Influent



B. Cutting Segment of 36 in. Swirl Influent for placing New Sampler.

Figure 61. Photographs of EDP Technologies Cross-Sectional Sampler installations.

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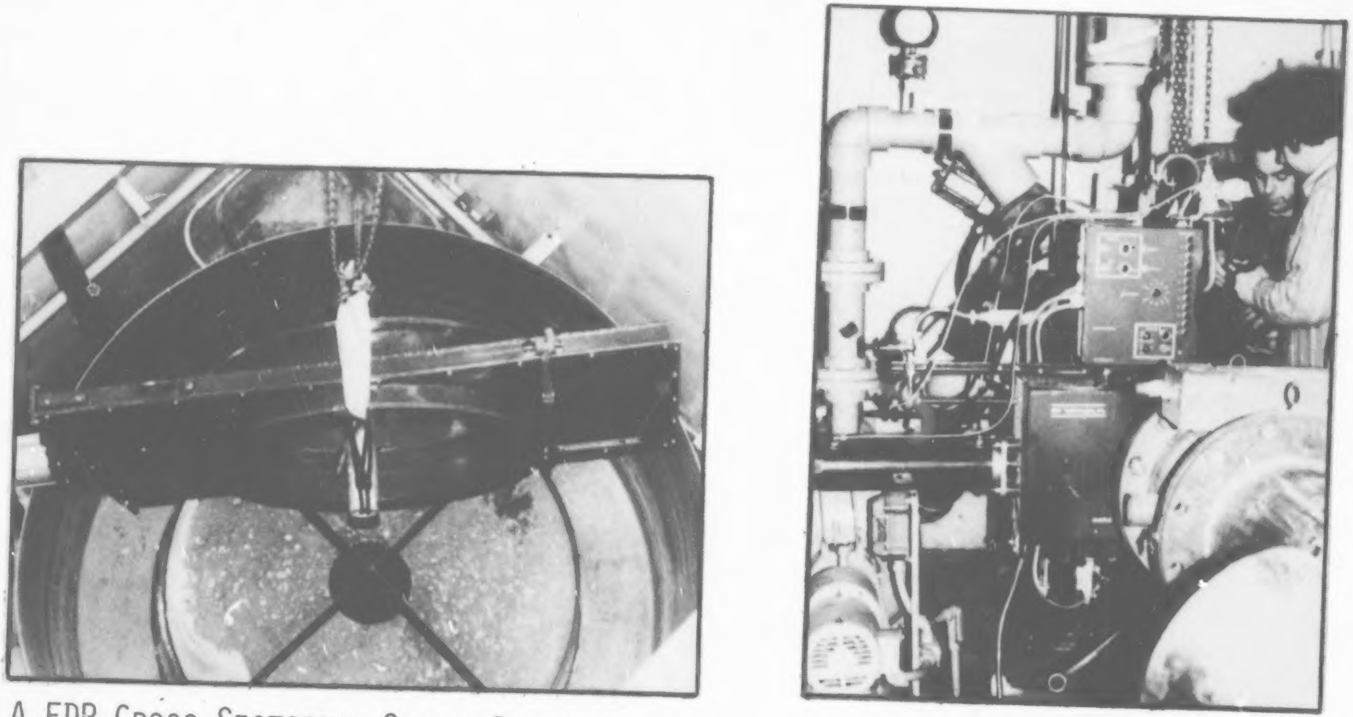
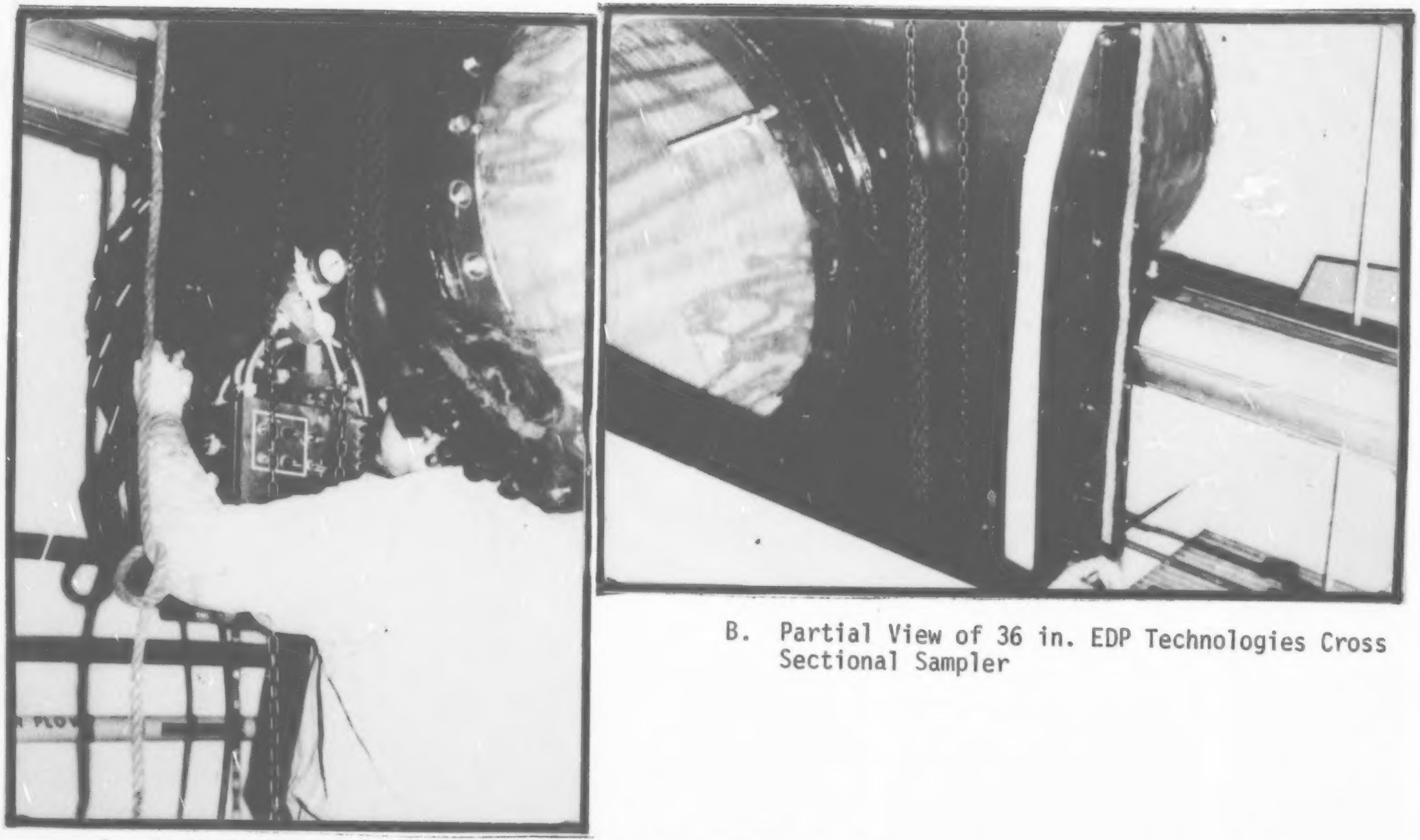


A. EDP CROSS-SECTIONAL SWIRL INFLUENT SEWER SAMPLER - LOWERED INTO BASEMENT FLOOR (SWIRL DEGRITTER APPEARS BELOW)

B. EDP CROSS-SECTIONAL SWIRL FOUL SEWER SAMPLER INSTALLED

Figure 62. Photographs of EDP Technologies, Inc. Cross-Sectional Samplers.

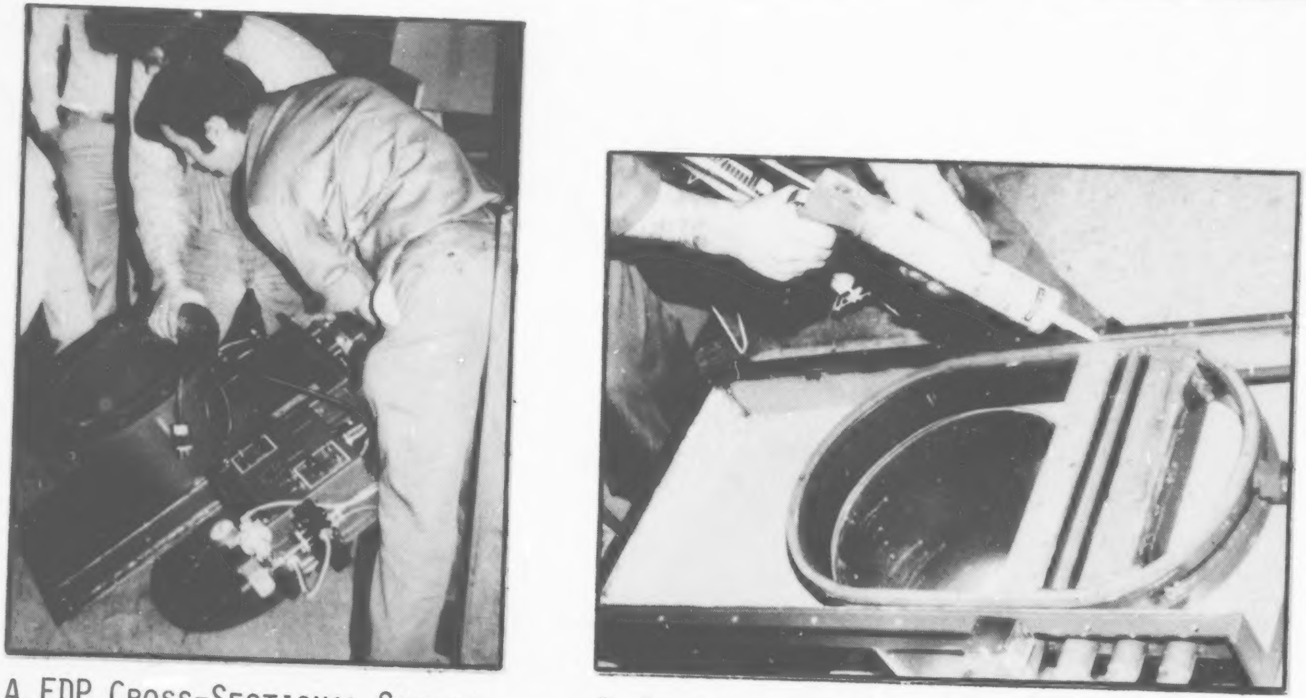


A. Partial View of 36 in. EDP Technologies Cross Sectional Sampler (Control Assembly behind Engineer)

B. Partial View of 36 in. EDP Technologies Cross Sectional Sampler

1 in = 2.54 cm

Figure 63. Photographs of EDP Technologies Cross-Sectional Samplers.



A. EDP Cross-Sectional Swirl Foul Sewer Sampler - Completed

B. Inner Assembly EDP Cross-Sectional Swirl Foul Sewer Sampler

Figure 64. Photographs of EDP Technologies, Inc. Cross Sectional Samplers.

and pressure gages for operational setup and monitoring. The containment shell of the 12 in. (30 cm) pipe sampler with the cover plate removed is shown in photograph B, Figure 64. The rectangular piece section is the containment shell which encloses the oval sample cell slide. The sample cell is the rectangular piece within the oval section. The driving arm from the air cylinder would be attached to the nut seen on the right.

Photograph B, Figure 62 displays the Swirl Degritter sampler, the 1.5 cfs (42.5 l/s) Hydro-Brake, the Discostrainer feed pump and pvc feed line and the Fisher-Porter magnetic flow meter. Wastewater pases through the sampler, then the flow meter followed by the Hydro-Brake and then into the Degritter (not shown). Discostrainer pump feed is taken from a port upstream of the sampler. All components of the complete sampler are visible in this photo including the air cylinder attached to the left of the containment shell, the control panel on top and the sample cell drains at the base of the shell. The relative size of the 12 in. (30.5 cm) pipe sampler can be determined by reference to EDP personnel in the three photos.

## Section 11.2.4. Lancaster Swirl Evaluation Project Flow Meter Calibration

### METER PROBLEMS

Flow meters were installed on the 3 ft (91.4 cm) diameter influent pipe to the Swirl Concentrator and on the 12 in. (30.5 cm) foul underflow leading to Swirl Degritter. Flow into the facility is determined by the combined sewage and stormwater runoff volume of the drainage area while flow through the 12 in. (30.5) line is limited by a Hydro-Brake with a maximum rate of 1.2 cfs (34 l/s).

The foul underflow meter is a Fisher-Porter Magnetic Meter which was laboratory-calibrated by the Alden Research Laboratory. Field results indicate the maximum flow rate through the foul line to be that for which the Hydro-Brake was designed. It was assumed that the meter was operating and recording properly and field calibration was not required.

The 3 ft (91.4 cm) influent pipe is monitored by two flow meters. One is a Mapco (Model 8000) Nusonics Flowmeter which relies on sound velocity measurement for flow rate determination. For reasons unexplainable by the manufacturer, this meter fails to record flow until approximately 15 minutes after the tranducers are submerged. This period also corresponds to a time of high flow regimes. It is possible that excessive influent flow velocities transpose the sonic waves downstream of the receiver causing a zero response (although the manufacturer disagrees with this theory). The meter operational mode is indicated by flashing light. However after a complete record of the light sequence by EDP and Lancaster personnel, the manufacturer could still not trace the problem. As a consequence an additional Leeds and Northrup, 475 Doppler Flowmeter was also installed in early 1979. This device seldom operated properly since initial installation and was malfunctioned during all but one storm event during EDP's evaluation. This meter was inspected by the manufacturer's representative in October 1980. It was removed, repaired and reinstated in late November, 1980. Short term full-pipe low level flow could be produced by backing up the swirl. Under this condition the repaired unit appeared to operate properly.

During a storm event on April 2, 1981 the Swirl level sensor worked properly and both influent meters operated. Due to the historical problems with the flow meters EDP scrutinized the chart ouputs and influent flowmeter discrepencies were discovered. It was noted that although the two meters disagree sharply in absolute values, the flow patterns were somewhat similar. Assuming that the Mapco meter was correct, a plot of flow rates indicated that the Doppler meter was probably recording flows between 12 to 92 cfs (.42 to 3.25 $m^3$/sec). Doppler flow rate data based on an assumed span of 12-92 cfs are plotted in Figures 65 and 66. The revised Doppler flow rates agree with the Mapco flow rates, though it was still deemed essential to check the calibration of both meters.

EDP performed two studies to rectify problems with the influent meters. First, the Leeds and Northrup Doppler flow meter calibration was to be checked by dye tracer studies. It was believed that manufacturers' calibrations were not reliable. Second, diversion chamber and swirl water levels were related to flow rate through the 3 ft (91 .4 cm) pipe.

During the next storm event on May 10, 1981, the Doppler influent meter which had operated for the first time during the last event (April 1, 1981) failed again, and the Mapco unit exhibited the typical delayed response period. During the next event on the 15th of May, 1981 neither influent meter operated. As per the manufacturer's request the results of EDP's observations were forwarded to Mapco with the hope of alleviating further meter problems. Based on the continual failure of these meters EDP developed a method for estimating influent flow rates based on the rate of Swirl tank fill and relative Swirl and diversion chamber levels. This method was used whenever necessary to roughly estimate flow data.

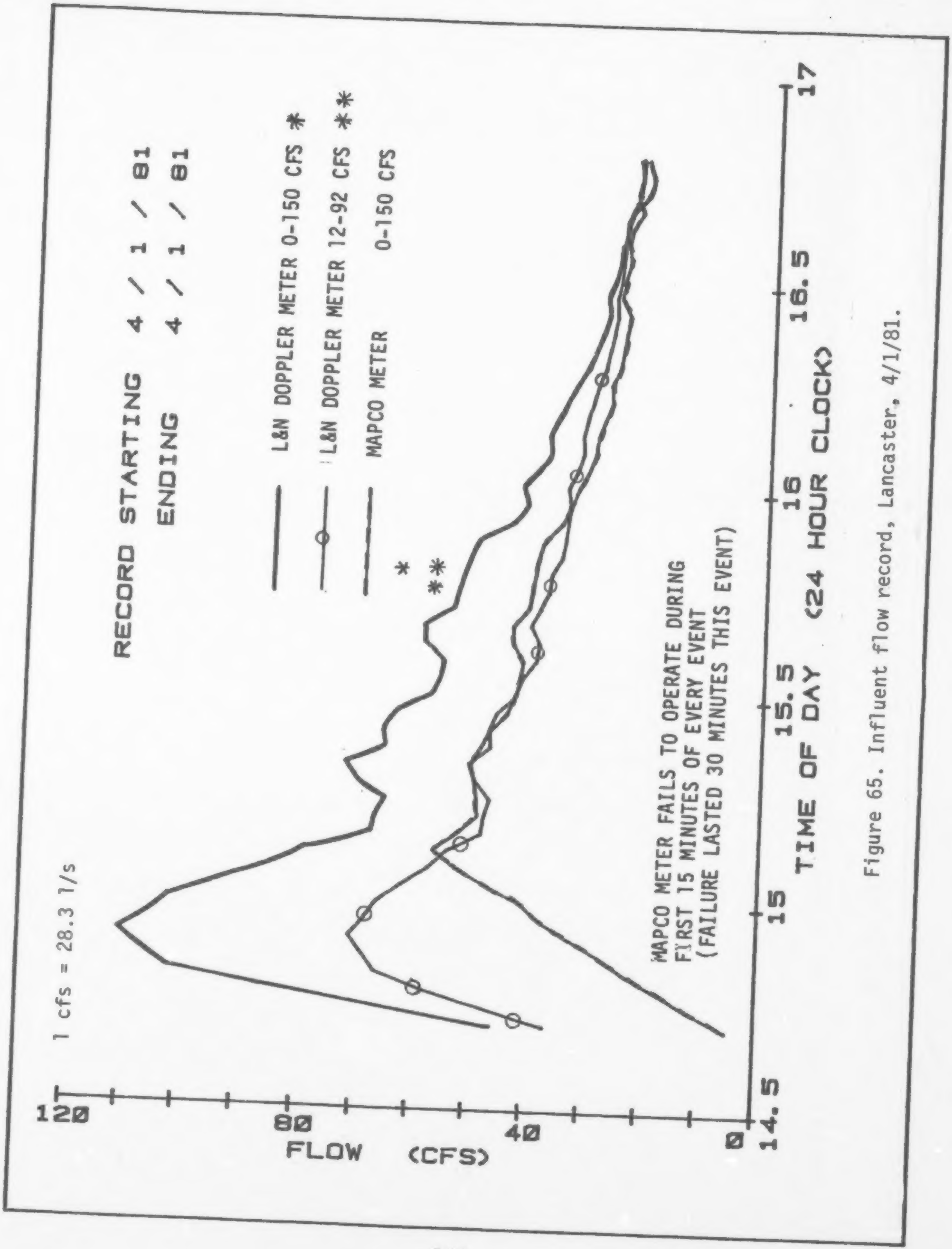


Figure 65. Influent flow record, Lancaster, 4/1/81.

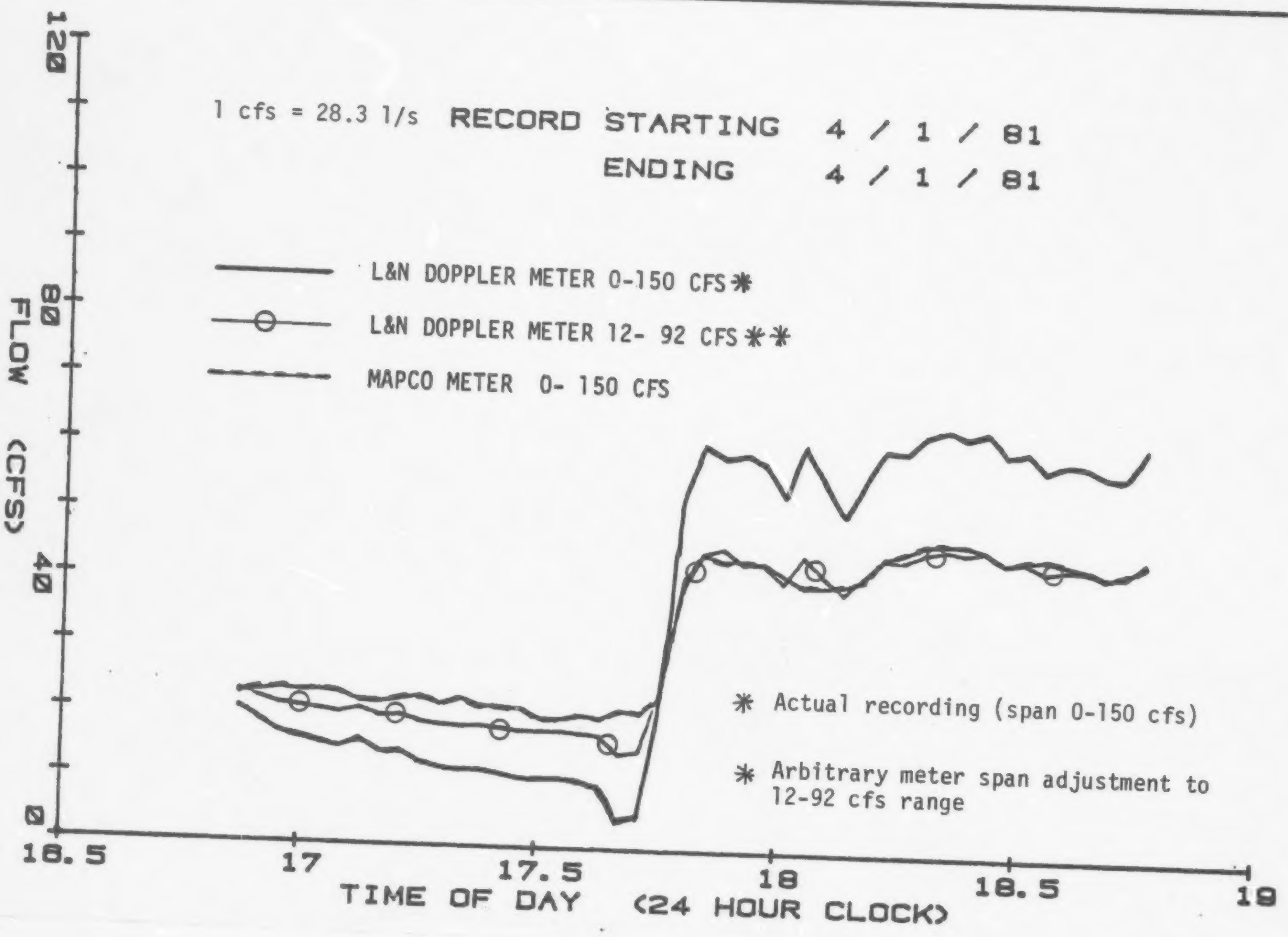


Figure 66. Influent flow record 4/1/81 (continuation), Lancaster.

## EMPIRICAL RELATIONSHIPS

An initial attempt was made to relate Swirl influent flow to clear and foul flow rates. Accurate determination of the clear water flow rate proved to be unreliable due to:

1) The large diameter of the Swirl clear water weir, allowing a substantial change in flow with a slight change in depth over the weir.

2) The Swirl weir is not level all around. Attempts to level the weir were not completely successful. Although final position measurements were taken after adjustments it was expected that warpage would continually occur rendering the use of the circular weir equation of questionable accuracy.

3) The flow over the clear weir does not directly relate to the instantaneous inflow since there is some lag time as the tank level increases. Influent rate is related to the change in tank depth as well as the actual level.

The next attempt was to assume the system consisted of two tanks, that is, the diversion chamber and the swirl connected by a pipe acting as a syphon. Basic hydraulics would dictate that the flow between the two units would be directly related to the differences in water levels.

A plot of measured flow versus Swirl levels (as shown in Figure 67) indicated a range of flow for any given Swirl level. This range is probably due to the fact that the liquid within the tank is not quiescent but flowing freely. Inspection of Figure 67 indicates that the head differential between the diversion chamber and Swirl liquid levels accounts for much of the variation cited above. The data for this plot were taken from the liquid level records and the Mapco meter influent flow record for the storm of 10/2/80.

Multiple linear regression analysis of these data (29 points) taken directly as flow, Q, (cfs) swirl level (S.L.) (ft) and diversion chamber level (D.L.) (ft) resulted in the equation:

$$Q = 11.234 \times S.L. + 34.162 \times D.L. - 302$$

The coefficient of determination $R^2$ is 0.983. The correlation between actual Mapco flow and the calculated flows is good. There are several limitations as to the application of this equation. First, the equation is functional only for times when the Swirl level is above the clear overflow weir level of 6.2 ft (189 cm). Below this level the equation is inaccurate, however tank rate fill calculations can be used. Second, no Mapco flow

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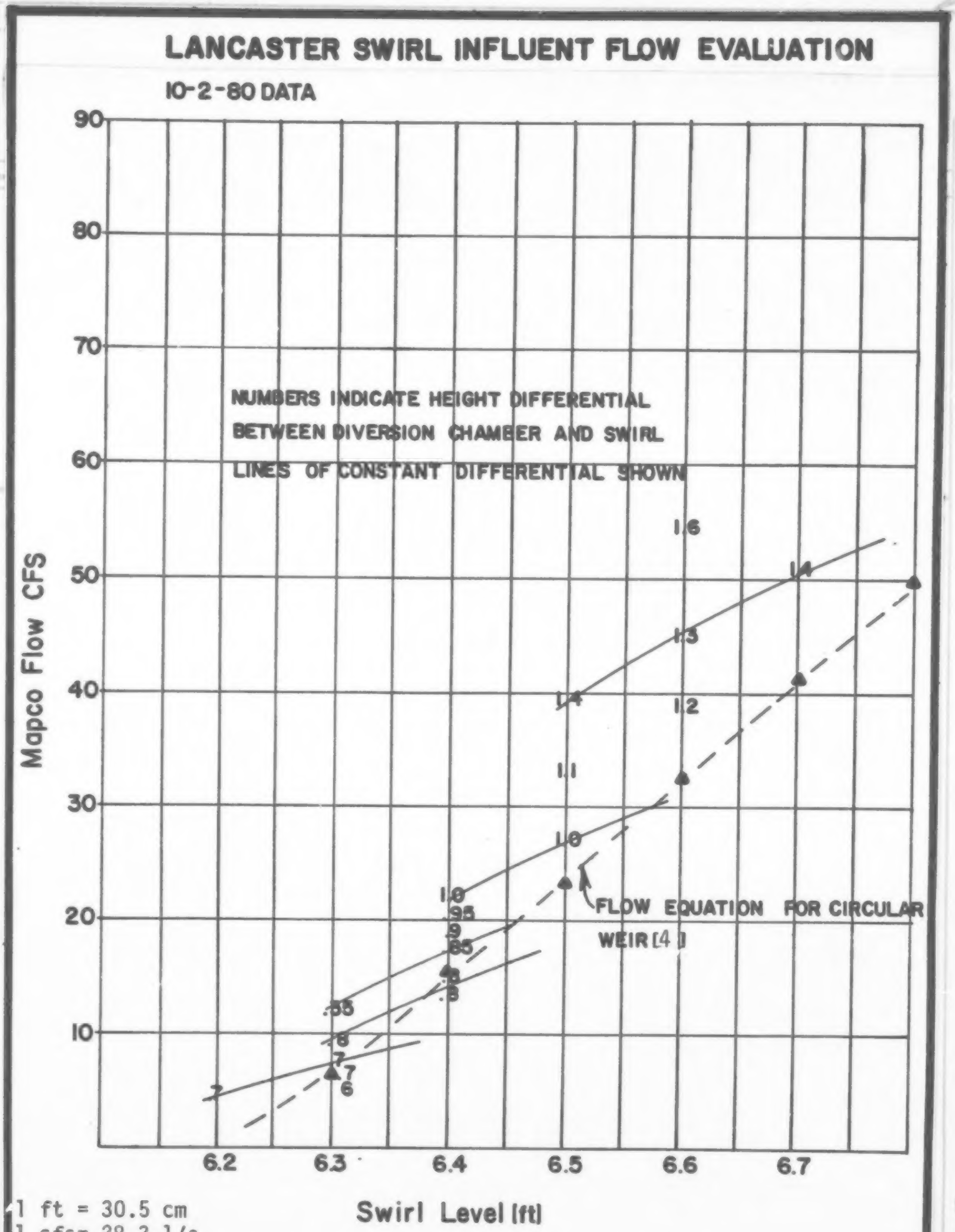

1 ft = 30.5 cm
1 cfs= 28.3 l/s

Figure 67. Plot of swirl level vs Mapco meter flow (10/2/80).

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data was available for flow rates less than 4.5 cfs (127.4 l/s) and the resultant equation tends to inaccurately indicate flows below this level. Since most of the time storm flow is above 5 cfs (141.6 l/s) this created no problem. Any flows calculated to be below this level using the equation were manually reviewed using tabular data. The raw data were selected from a portion of the storm level of 10/2/81 when the two level sensors and the Mapco meter were all operating. During this time the diversion chamber level varied by 2 ft (61 cm) and the Swirl level varied by 0.7 ft (21.3 cm).

It was desireable to determine a relationship between the Swirl and diversion chamber levels which can be used to determine the influent flow rate for all storm events. Data from a second storm event (11 points) were evaluated in this regard. For the event of 5/15/81 the equation developed was:

$$Q = 15.3 \times S.L. + 51 \times D.L. - 230.5 \quad R^2 = .981$$

Although a different equation resulted, as expected, the correlation was again high indicating a reasonable relationship between Swirl and diversion chamber levels and the flow rate. Figure 68 shows comparison of measured and predicted flows for the 5/15/81 event.

Although good correlation between Swirl levels diversion chamber levels influent flow rates exist as seen by the events of 10/2/81 and 5/15/81, the equation developed for either data set could not represent the flow rates during the other event. This difference is shown in Figure 69 wherein the equation generated using the 5/15/81 data was used to estimate flow levels for the 10/2/80 event. A positive overestimate of 25 cfs (708 l/s) results. The relationships are dependent upon Swirl and diversion chamber levels as indicated on the level sensor records. These records are subject to three possible errors: a) the field calculation of the sensing unit the possibility of a slight misadjustment of the zero or span settings); b) strip chart recorder; and c) interpretation of the strip chart lines.

The discrepancy in flow values cited above is probably due to the misrecording of liquid levels rather than in the equations developed. The following analysis indicates that this is the case. First, a review of data for the two events was made to compare data points with similar values for the Swirl level and actual flow rate. Results were as follows:

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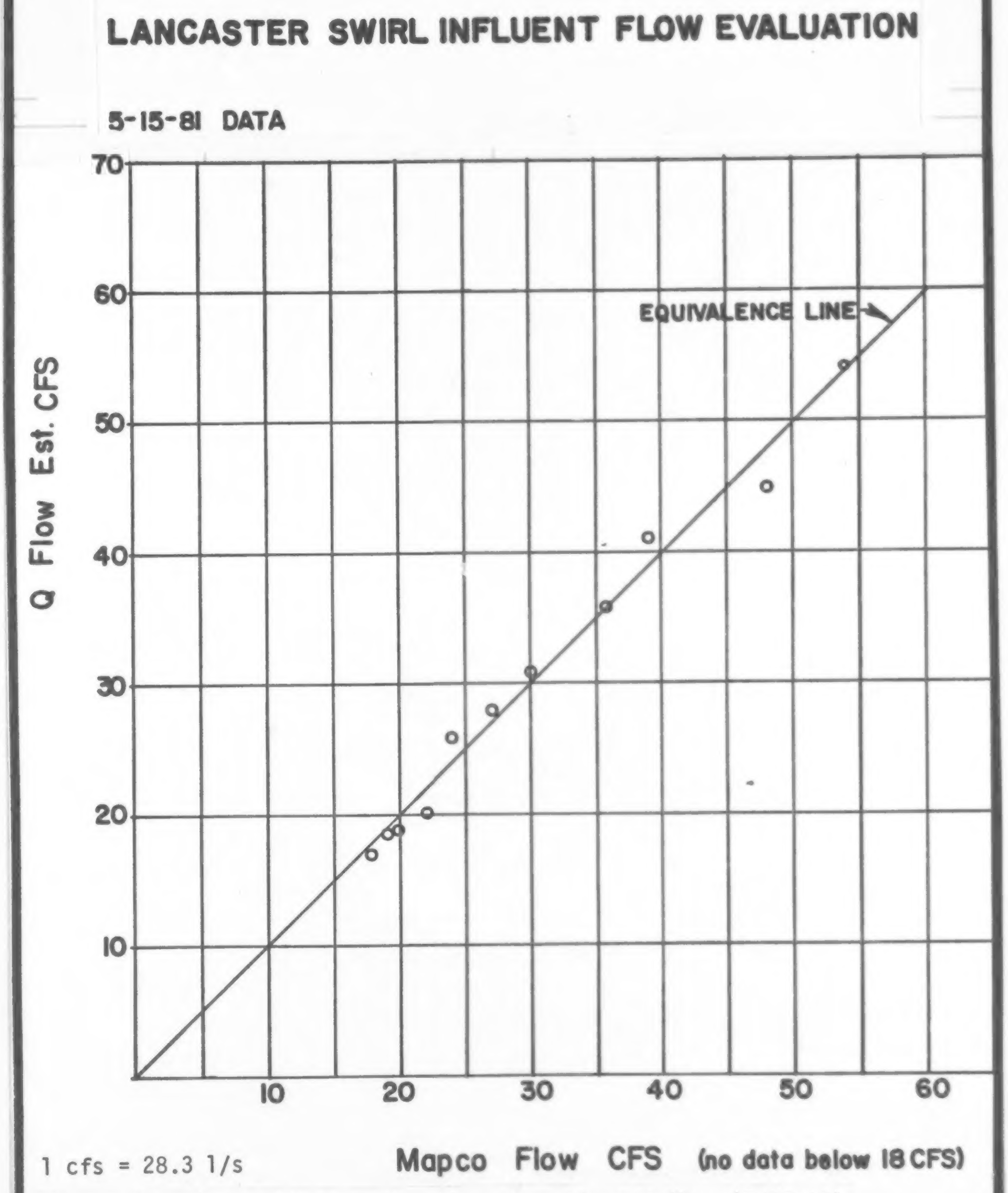

1 cfs = 28.3 l/s

Figure 68. Plot of Mapco meter flow vs estimated flow (5/15/81).

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Storm of 10/2/80

| Q (cfs) | Swirl Level (ft) | Div. Cham. Level (ft) |
|---|---|---|
| 39.6 | 6.6 | 7.9 |
| 36.7 | 6.6 | 7.8 |
| 19.6 | 6.4 | 7.3 |

Storm of 5/15/81

| Q (cfs) | Swirl Level (ft) | Div. Cham. Level (ft) |
|---|---|---|
| 41.0 | 6.6 | 7.3 |
| 36.1 | 6.6 | 7.2 |
| 18.6 | 6.4 | 6.8 |

The difference in diversion chamber values for near equivalent swirl levels and flow rates was consistently around 0.5 ft (15.2 cm). The bias noted above for Figure 69 disappears if the diversion chamber levels of the 10/2/80 storm event were reduced by 0.5 feet (15.2 cm) and then used in the second (5/15/81 data) equation to estimate flow values. It is clear that with this correction flow values calculated agree with the actual values quite closely.

It appears that the probable error is in the diversion chamber level record. Of the three error sources cited above, setting of the recorder within the diversion chamber is most likely. The recorded data were reviewed several times to minimize any manual interpretation error and 0.5 ft (15 cm) is quite large to be a field calculation error. As previously stated, the strip chart resolution is quite poor with an incremental value of 0.4 ft (12.2 cm) per line. A minor adjustment error would easily produce a 0.5 ft (15 cm) discrepancy. In summary, the method of determining flow rates from relative swirl and diversion chamber liquid levels was reasonably effective. This empirical procedure was roughly calibrated using dye/tracer methods.

### Dye Calibration of the Swirl Flow Monitoring System

Dye studies were performed during five events at the Lancaster Swirl site. Evaluation consisted of adding dye slurry to the Swirl influent at the diversion chamber. The concentration and flow rate of the dye slurry were known and samples were collected as the flow entered the Swirl. The dye injection system contained a circular ring with eight injection ports designed to allow the added dye to penetrate and mix with the entire waste stream. With the additional mixing in the influent pipe it was assumed that complete mix would be accomplished. Dye concentrations within the influent samples were determined and continuity considerations were used to calculate instantaneous flow rates.

Using this system dye calibration studies were performed during five storm events including, July 2nd, 20th am and pm, 28th and August 3rd, 1981. Neither the Mapco flow meter nor the

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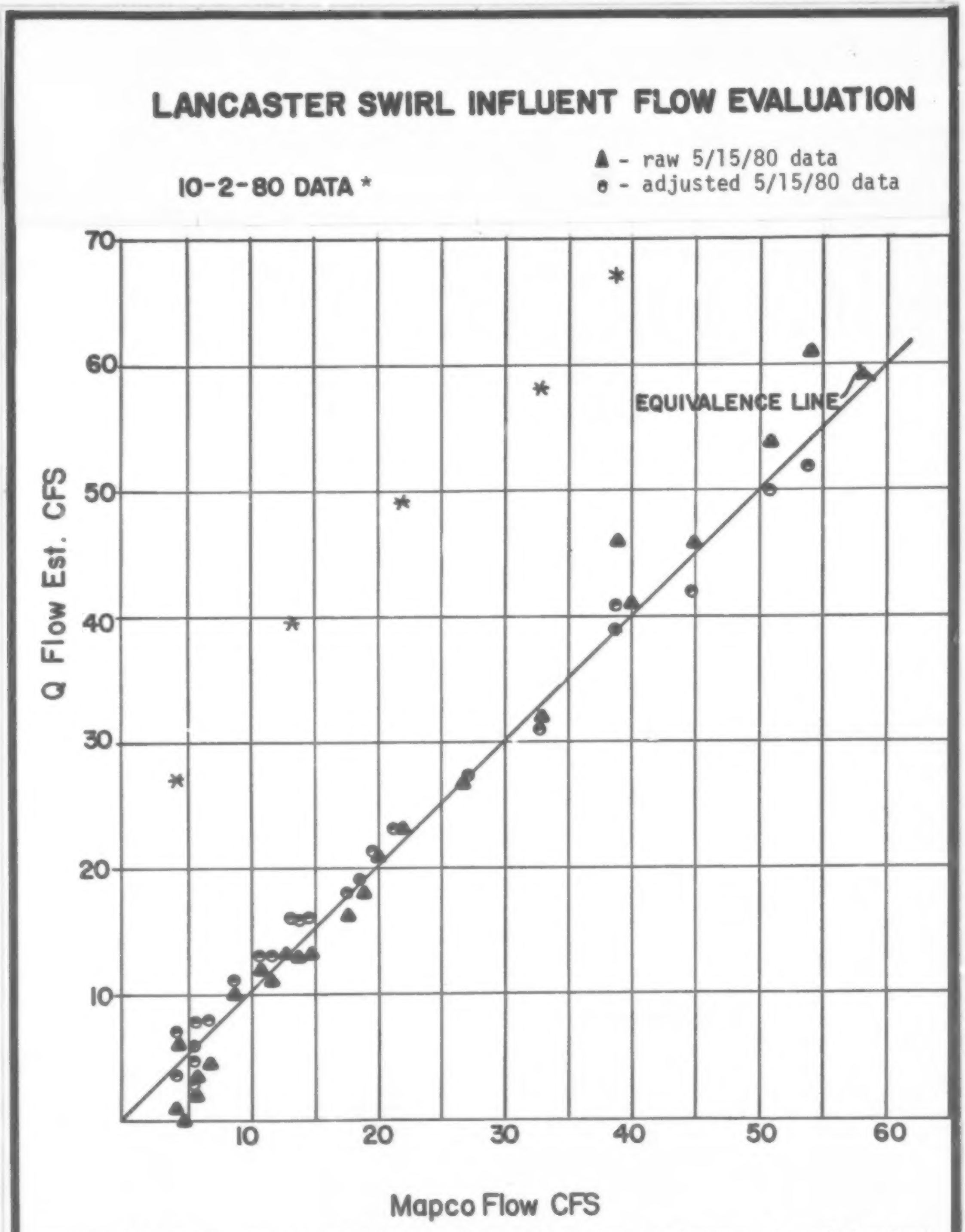

Figure 69. Plot of adjusted Mapco meter flow vs estimated flow (10/2/80).

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Leeds and Northrup flow meter were operational during any of these events. Results of flow rate calculations were compared to results of flow estimates based on relative swirl and diversion chamber liquid levels. Flow estimates were based on the results of earlier analysis comparing these liquid levels to Mapco meter flow records.

During this period the primary emphasis during a storm event was to manually collect samples for settleability analysis and since the dye study system also required manual sampling, dye/tracer experiments were typically not begun until late in an event. At that point flows had usually diminished and the Swirl and diversion chamber liquid levels were low. Although a series of samples were collected over a period of time the change in flow rate was small and relatively similar for each event (probably due to the backwater and downdraw characteristics of the drainage area). The net result was that only a small range of flow could be calibrated.

Based on these calibrations the flow rates as estimated by the liquid level method (and the Mapco meter readings on which they were originally based) were within a reasonable range of the actual flow as measured by dye experiments. For example,the flow estimates ranged from 6.2 to 9.5 cfs (175 to 269 l/s) for a seventeen minute period on the July 28, 1981 event while the calibrated flow changed from 5.4 to 9.6 cfs (153 to 272 l/s). Considering the errors entailed in strip chart evaluation and dye addition/concentration analysis techniques, these values are virtually equal.

## Summary

Influent flow records at Lancaster were reviewed for accuracy by three methods.

1) Mapco flow records were usually available, but only after the first 15 minutes of each event. This period usually covered the time of high flow. For one storm event flow records were produced by the Doppler meter. Flow data could be made to agree using arbitrary adjustment assuming the Mapco values to be correct.

2) Mapco flow values were compared to relative swirl and diversion chamber liquid level and to overflow based on the circular weir equation. The circular weir equation failed to demonstrate agreement with Mapco values. For any given Swirl liquid level the weir equation yields a constant value while the diversion chamber level and Mapco values varied.

For one event an equation was developed which accurately calculated Mapco flow values based on Swirl and diversion chamber levels. For other events it was necessary to adjust the equation to produce agreement with Mapco values. This adjustment consisted of a slight change in the recorded diversion chamber level. For each event the amount of charge varied typically up to 0.5 ft (15.2 cm). The need for this change was due mainly to the poor resolution of the diversion chamber level chart where each minor scale diversion represented 0.4 ft (12.2 cm). As with method 1 above the repeatability of data comparison indicates good precision but does not ensure the accuracy.

3. To determine the accuracy of flow records a dye injection system was used to determine flow rate. The intent was to use the system at several flow rates during an event and compare results to Mapco values. Even a single point would have sufficed to determine accuracy. Unfortunately the Mapco meter was non-operational during dye study testing. In addition, dye study results, although including many samples, were all within a narrow range of flow. Adjustments could be made to liquid levels to yield agreement at the one flow point but no additional points were obtained.

The precision of the Mapco flow records seems reliable based on the one-time agreement with adjusted Doppler values. The accuracy was never adequately tested. In sum, extensive efforts were expended trying without success to make operational the flow meters and at the same time develop reasonable flow calibrations. Unfortunately, all influent flow values cited in Chapter 12 must be viewed as reasonable "ball-park" estimates.

## Section 11.3 Instrumentation Overview - West Roxbury

### Details of Sampling Locations

The initial sampling program at W. Roxbury site consisted of six hand-sampling locations noted on Figure 70. Samples were collected during storm events throughout the evaluation period and analyzed for solids concentration and COD.

Further into the evaluation period Manning automatic samplers 6000 series were used to collect foul samples from both units. (See Figure 70 for sampler locations). These samplers were installed to monitor the foul flow before it entered the discharge line where sedimentation could take place.

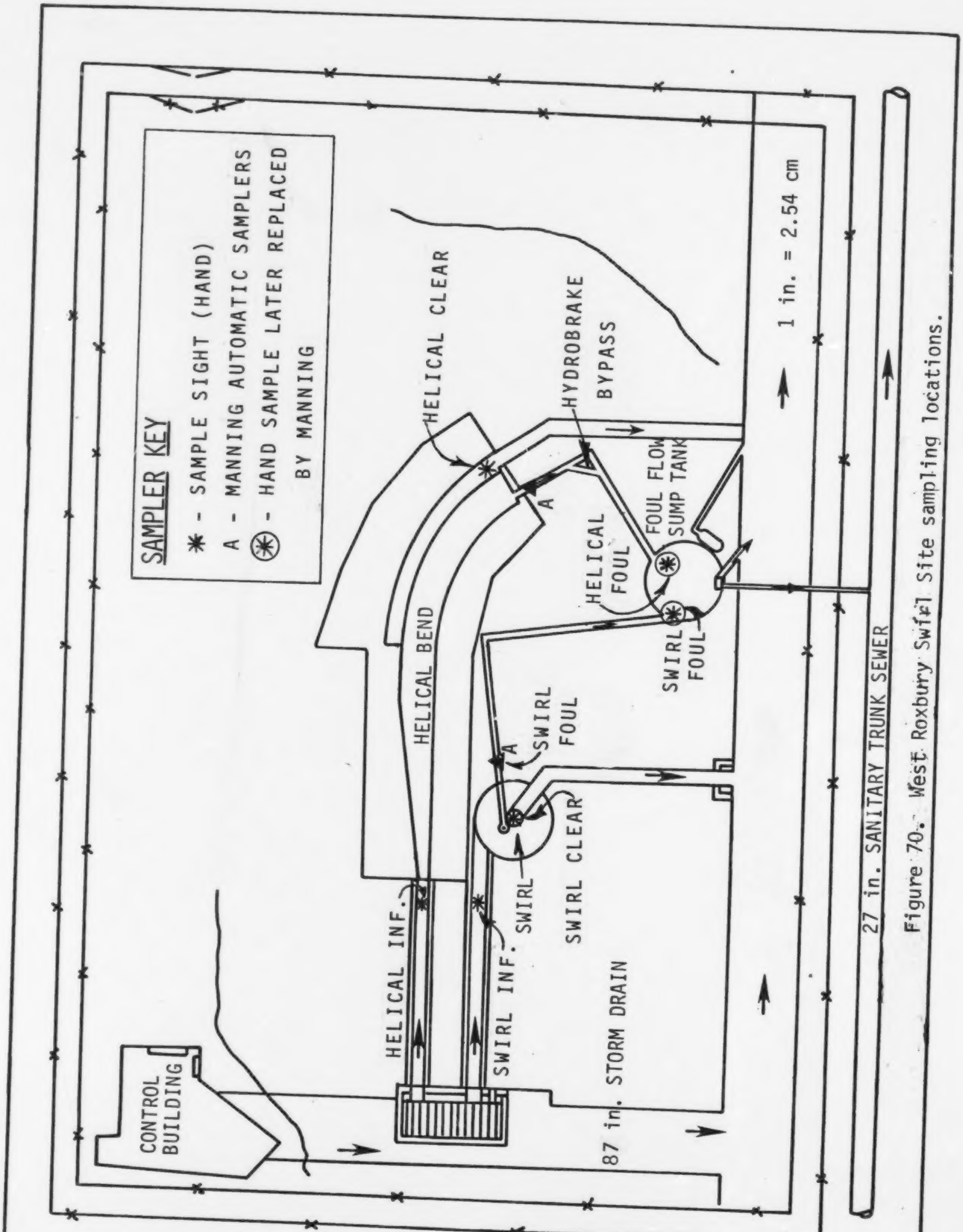

SAMPLER KEY
✳ - SAMPLE SIGHT (HAND)
A - MANNING AUTOMATIC SAMPLERS
⊛ - HAND SAMPLE LATER REPLACED BY MANNING
CONTROL BUILDING
HELICAL INF.
SWIRL INF.
HELICAL BEND
HELICAL CLEAR
A
HYDROBRAKE BYPASS
HELICAL FOUL
FOUL FLOW SUMP TANK
SWIRL FOUL
A
SWIRL FOUL
SWIRL
SWIRL CLEAR
87 in. STORM DRAIN
1 in. = 2.54 cm
27 in. SANITARY TRUNK SEWER

Figure 70. West Roxbury Swirl Site sampling locations.

## Sample Collection Methods

During the sampling program both automated and manual techniques were employed. Since EDP field crews were able to be on-site during most of the runoff events, grab sampling techniques were used for those events.

Initially influent samples were taken manually in one l wide-mouth plastic bottles for both the Swirl Concentrator and Helical Bend units. Manning samplers were later installed for influent sample collection but were found to obtain the same quality of sample as manual procedures so they were removed. Typically, samples were collected from the start of the event until unit shut down in 4 minute intervals.

All clear water samples from both the Swirl Concentrator and the Helical Bend units were taken manually during each event. Samples were collected at the same 4 minute intervals until unit shut down when flow over the clear everflow weirs had ceased.

Foul sewer samples originally taken by hand from the units at the outlet port showed unusually low solids concentrations which prompted the installation of automatic Manning samplers prior to the discharge line. Concentrations of solids from these samples were much higher indicating that a considerable amount of solids were settling within the discharge line. The Manning samplers were set at 3.75 minute intervals and were initiated at the start of the event and continued sampling after unit shutdown throughout the drawdown period. During the first minutes of tank drawdown the samplers were triggered manually at shorter time intervals.

Several tank samples were collected during storm events from each unit. A specially designed sample bottle holding device was constructed to obtain cross-sectional or single depth samples. Initially, a sample bottle was loaded in the device and the trigger released tightly sealing the bottle. The bottle was lowered in the tank to the appropriate depths(s) and the trigger mechanism pulled, allowing the bottle to fill. Release of the trigger mechanism would close off the sample bottle.

Settling column samples were collected in four gal (15.1 l) buckets (8 for each test) from influent, clear and foul flows. The majority of the samples were collected at the start of the storm event. Influent samples were taken in the inlet channel downstream of the flow monitoring transducer and prior to the inlet into the units. Clear water samples were collected in the overflow pipe so as to achieve an equal mix of flow passing over the entire clear overflow. Foul sewer samples were taken during events early in the evaluation period but were discontinued when it was discovered that foul solids were settling in the discharge lines of the units.

Monitoring of precipitation was conducted using an automated recording rain gauge located on-site.

## 11.4 Procedure for Determination of Settleability Characteristics

A major aspect of the Swirl evaluation was comparison of solids concentrations and settling velocity characteristics of the material suspended in the influent and clearwater wastestreams. Various types of settling column designs and operational procedures were received by EDP in a previous study to develop a procedure for determining CSO and stormwater settleability characteristics. (33) Pertinent details of that report and final results are included in section 11.4.1.An on-site settling column was used in a limited fashion in Lancaster and is described in section 11.4.2.

### 11.4.1. Settling Column Design

Three design parameters emerged from EDP's study (33) as the prime design determinants for the new envisioned settling column/procedure. These parameters included settling column dimensions, mixing capabilities and sampling intake systems.

The first design consideration was the size of the settling column diameter relative to the quantity of sample drawn from the column at each prescribed time interval. A related consideration is the time necessary to fill the drawn sample. The issue centers on the comparison of rate of settling column water surface drawdown relative to settling particle velocities.

The second design parameter involved standardizing column mixing mechanisms and procedures. Typically, column mixing has been accomplished by manual efforts such as hand-operated rotation and stirring or by use of compressed air. These methods create undesireable characteristics including solid degredation, floculation, agglomeration, incomplete mixing and generation of eddies and currents. The settling column design therefore focused on a method of consistent controlled mixing aimed at minimizing the aforementioned problems. The design chosen encompassed steady state, bi-directional (axial/longitudinal) rotation. Two electric motors with variable speed controllers provided uniformity and flexibility to the mixing process. Axial rotation creates a uniform distribution of solids across a cross sectional area of the column. The longitudinal rotation is the mechanism by which the solids would be dispersed throughout the horizontal axis of the column.

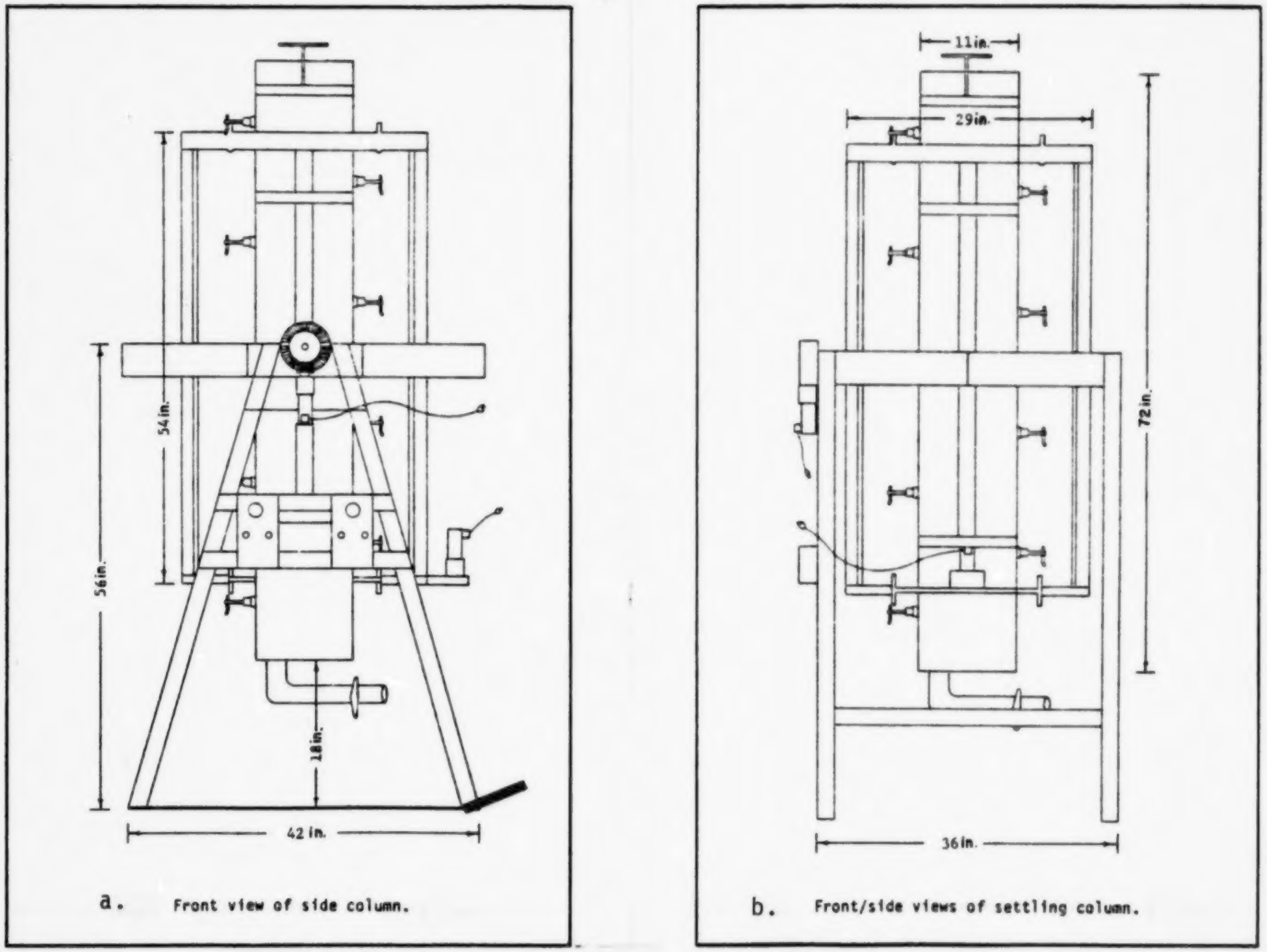
The third design parameter dealt with the sampling port mechanisms. A push-rod type sampling intake device was chosen to minimize interference with settling particles. Nine sampling ports were included at six in. (15.24 cm) intervals, alternating at 180 degrees. Intake tubing with a diameter of 0.40 in. (1.02 cm) was used to assure large solid sampling capabilities and minimal sampling time. Each of the nine intake asemblies was designed to draw a sample from the center of the column and then be withdrawn to a flush seal on the side of the column. The discharge side of the intake was attached to a permanent threaded cap acting as a positive fastening mechanism for the sample bottles.

## Settling Columnn

Front and side mechanical views of the settling column are presented in Figures 71-A and 71-B. A photograph of the unit is shown in Figure 72-A. The base cylinder is 0.26 in. (0.66 cm) thick-walled tempered acrylic measuring 6 ft (1.83 cm) length with an inside diameter of 11 in. (27.94 cm). Constructions performed on the base column included nine sliding push-rod sapling ports, three mixing stators, and a base with a drain valve.

Each sampling port consists of 0.43 in. (1.09 cm) diameter intake tube, a water-tight flush intake seat on the inside of the column and the threaded cap attached to the discharge end of the tube to allow bottles to be positioned prior to the required sampling time. The bottom plate was also constructed of acrylic and fitted with a 2-in. (5.08 cm) drain valve to facilitate sample removal. The top seal was fabricated by fitting a piece of compressible rubber between two aluminum plates designed to be hand-tightened together, thus forming a compression seal around the perimeter (see Figure 73-A).

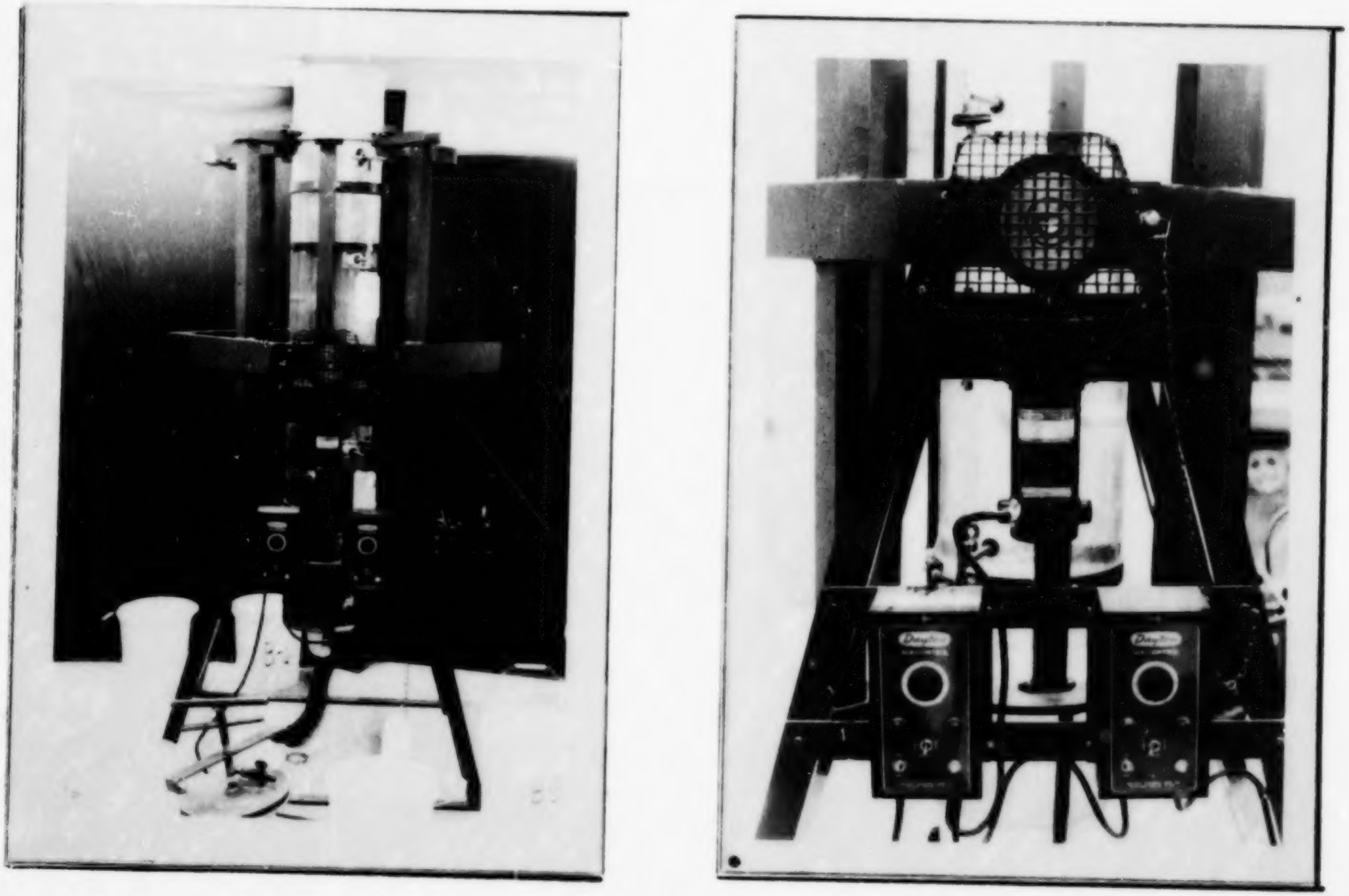
To support the axial rotation assembly (see Figure 73-B) an inner framework was constructed of light gauge aluminum, capable of supporting one drive motor. This frame then was fastened into a support structure which besides elevating the settling column, supported the longtitudinal rotary drive motor and provided a mounting for the speed controllers. The two drive motors selected were capable of supplying a maximum of 5 and 7 rpm for longitudinal and axial rotation, respectively. A photograph of the two speed controllers are shown in Figure 72-B.


11in.
29in.
72in.
54in.
56in.
18in.
42 in.
36in.

a. Front view of side column.

b. Front/side views of settling column.

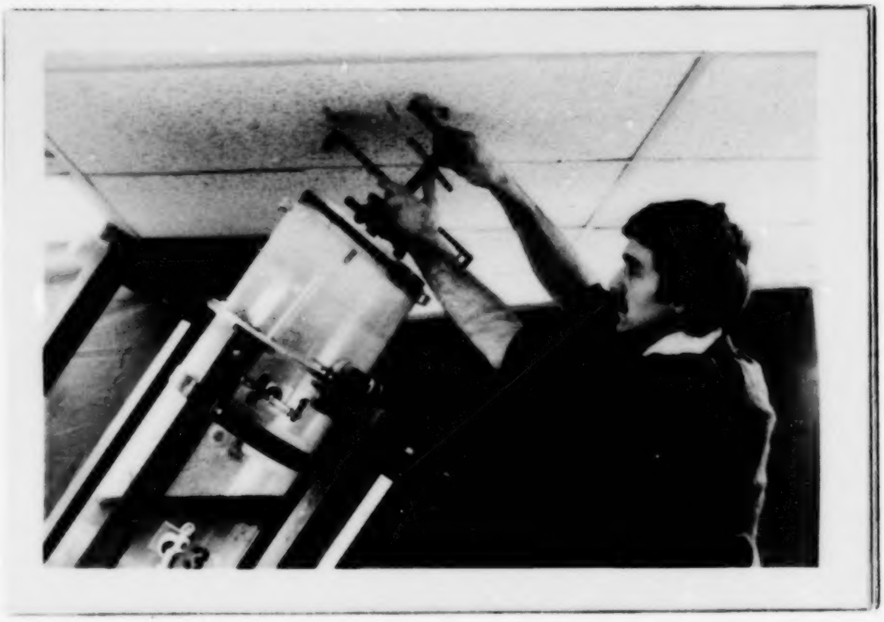
Figure 71. Front and side views of motorized settling column. 1 in. = 2.54 cm.



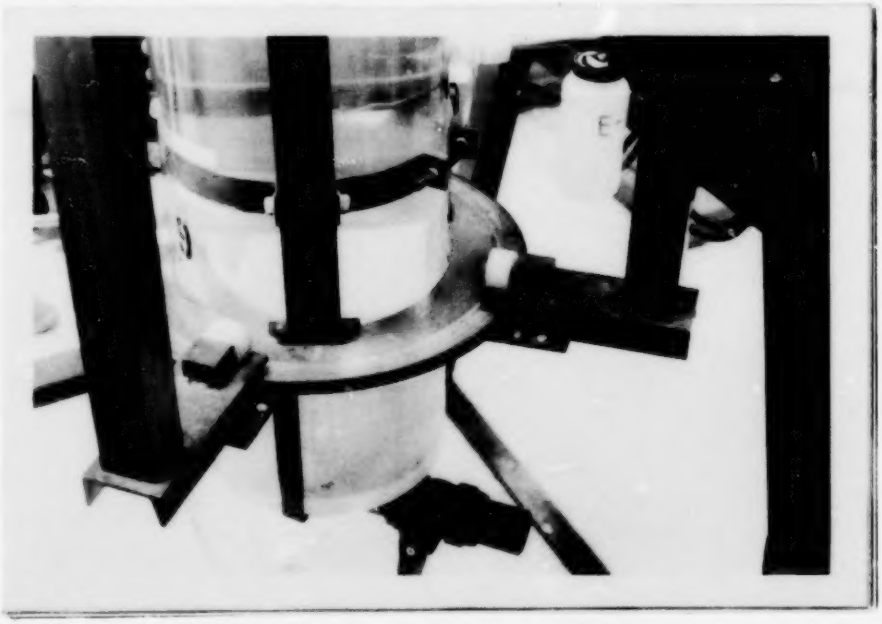
A. Settling column

B. Axial and longitudinal motorized assembly controllers.

Figure 72. Photographs of motorized settling column.



A. Hand-tightened top water seal.



B. Lower portion of axial rotation assembly.

Figure 73. Photographs of settling column mechanical details.

## Settling Column Operational Details

Air-tight sample containers were completely filled in the field and capped carefully so as to minimize air entrapment. The reason for this procedure was to reduce the potential for breakdown of large organic solids. All containers collected at the West Roxbury site were then packed tightly together in the transport vehicle to prevent excessive movement. Containers from the Lancaster project were packed in cartons and air-freighted to Boston for testing. Quality was an unknown factor.

Once the samples were poured into the settling column a uniform procedure was developed to assure complete mixing and to minimize solids breakdown. The axial motion was first activated and set at a rotational speed of 5 rpm. Longitudinal rotation was set at a speed of 3 rpm. Mixing was continued for three full minutes. During the mixing procedure, all sampling port intakes were withdrawn from the column interior so as not to interfere with the suspended solids.

Immediately following cessation of column rotation, the first three samples were taken. Samples were drawn by sliding the intake apparatus into the center of the column, allowing the sample bottles to fill and withdrawing the intake following completion (see Figure 74). Samples were drawn into uniform 350 ml bottles and were capped immediately following removal from the settling column. All bottles were labeled consecutively. After each set of samples were taken, the next three bottles were screwed into the sampling ports and the liquid level in the column was recorded for future use in computing settling velocities.

The column sampling intervals were determined to begin at time zero, followed by samples taken after 30 seconds, 1, 2, 5, 15, 30, 60 and 120 minutes from time zero. Samples were always taken at the one ft (30.5 cm), three ft (91.5 cm) and the five ft (153 cm) column elevation.

No attempt was made in any of the settling column tests to distinguish between rise (floatables) and fall (settleables) particle velocity distributions. Recent investigations at the Water Research Centre at Edinburgh, Scotland (34) devised methods and apparatus for separating particles into different rise or fall velocity groups. The settling column results presented in Chapters 12 and 13 represent gross overall particles settling characteristics independent of relative distributions of rise vs fall type particles. If a given sample tested had a significant fraction of rise (floatable) type materials then the resulting column test would bias fall velocities for settleable materials.

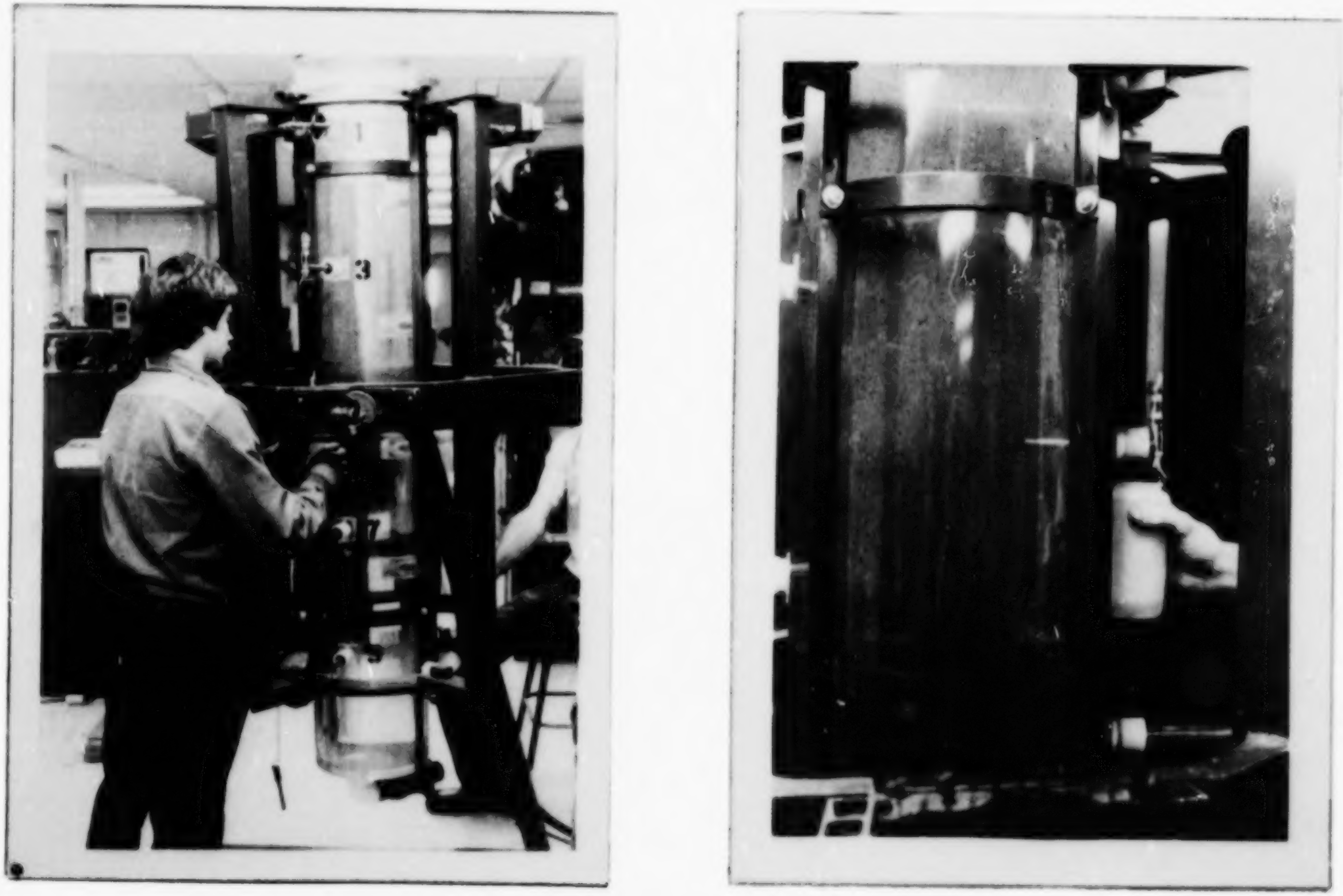


Figure 74.Photographs of settling column sampling operation.

### 11.4.2 Lancaster Settling Column

The Lancaster settling column was a stationary plexiglass unit 6 in. (15.2 cm) in diameter 70 in. (178 cm) tall with a total volume of 8.5 gal (32 l). The unit was not filled to the top to avoid spillage. The volume of sample used was 8 gal (30 l).

Sampling points were located at 1 ft (30.5 cm) spacings on the side of the column, flush with the inner wall and a valve on the outer tube end. Sampling consisted of turning the valve one-quarter turn, allowing drainage collection of about 100 ml of sample.

Since the settling column was stationary, initial mixing of the sample was accomplished by aeration at the base of the column. This was accomplished by attaching a diffusion stone to plastic tubing and lowering the stone into the column from the top. The stone could be rotated around the base of column by twisting the plastic tube to maximize the mixing operation.

The use of this aeration technique was reviewed in the EDP report (33) and found to be not as effective as the bi-directional mechanical mixing technique. The sampling ports, being flush with the inner wall, tend to collect samples from areas subject to wall effects. In addition, the column diameter affected the relative volume of the unit such that each sampling sequence lowered the water surface substantially and created substantial motion within the column.

### 11.5 Analytical Methodology

Solids Analysis (W. Roxbury and Lancaster)

Samples were analyzed for four solids fractions: suspended solids, volatile suspended solids, settleable solids and volatile settleable solids. The methods utilized for suspended and settleable solids determination were 208D (Total Nonfilterable Residue Dried) and a revised form of 208F (settleable matter) from Standard Methods. (34) The revised procedure consisted of several stirrings of the solids in an Imhoff cone as opposed to a single mix at the 45 minute point. Settleable solids were recorded at the end of the one hour settling time and 200 ml of supernatant were siphoned from the center of the cone midway between the surface of settled sludge and the liquid surface. The use of this procedure enabled the calculation of the weight of settleable matter as well as a visual reading of the volume of settleable solids within each sample. Determination of volatile suspended and settleable solids were made following Standard Methods Procedure 208E (Total Volatile and Fixed Residue at 550 (35).

Samples taken from settling column tests were analyzed for suspended and volatile suspended solids according to procedures 208D and 208E discussed above.

Bacterial levels of stormwater samples at West Roxbury facility were noted as Total Coliform using millipore filter technique (35).

Occasional sieve analysis of tank sediment samples and settling column sediment samples were also performed to determine grain size distribution of the material as well as organic and inorganic content. Each sediment sample so collected was air-dried, weighed and then a sieve analysis conducted. The sieve series employed and related grain size nomenclature were the following:

| Standard Sieve Number | Size Opening in. | mm |
|---|---|---|
| 8 | 0.0937 | 2.36 |
| 16 | 0.0469 | 1.18 |
| 30 | 0.0234 | 0.600 |
| 50 | 0.0117 | 0.300 |
| 100 | 0.0059 | 0.150 |
| 200 | 0.0029 | 0.075 |

Subsequent to the sieve analysis, each sieved fraction was fired to conduct a percent volatile analysis.

The COD values of samples collected were determined using the U.S. EPA approved ampule COD Digestion and Analysis System.(36) This method requires a 2.5 ml volume of sample to be digested in the ampule at 150 degrees centigrade for two hours. The ampule is placed into a spectrophotometer and analyzed. Each series of samples analysis was preceded by the preparation of a set of standards.

## 11.6 Efficiency Calculation Procedures

This section describes various means of computing the treatment efficiency and removal rates for the Swirl Concentrator and Helical Bend Regulator units evaluated in this study. A unit which removes 50% of the influent solids mass and operates at 10 % foul underflow is obviously much more efficient than a unit removing 50% of the influent mass while operating at 30% foul underflow.

First, the removal rate was defined as the percentage of influent mass contained in the foul underflow line. Second, efficiency was defined as the removal rate minus the percentage of flow in the foul underflow line. A unit operating at 10 % foul underflow containing 10% of the influent solids mass would have 0% efficiency since it acts merely as a flow - splitting device. The rate of removal would be 10%. Removal rates are not flow related and can be used to match design criteria for total removals. Efficiency values were used to optimize the unit design.

Examples of removal rate and efficiency determination follow. As can be seen it is not always necessary to determine the mass rates. An influent flow rate of 20 cfs (566.4 l/s) with 10% foul underflow will be used in all cases.

Example 1

Given an influent solids concentration, I, of 150 mg/l and a clear solids concentration, C, of 100 mg/l the efficiency equals the normalized decrease in solids concentration times the percentage of clear flow, CF, as follows:

$$\text{Efficiency, } E = (I-C)/I) \times CF/100$$

$$E = (150-100)/150) * 90/100 = 30\%$$

Removal rate, RR = efficiency plus percentage foul underflow rate, FF, that is, 30% + 10% = 40%.

Example 2

(Same determination as example 1 using mass calculations). Assume 20 cfs (556.4 l/s) influent and 2 cfs (56.6 l/s) foul flow:

| | |
|---|---|
| influent mass | IM = 150 x 556.4-56.6 = 84960 mg/s |
| clear mass | CM = 100 x 566.4-56.6 = 50976 mg/s |
| foul mass | FM = IM - CM = 33784 mg/s |
| RR= | FM/IM x 100 = 40% |
| E = | removal rate - foul flow rate = 30% |

Example 3

Given the influent solids concentration of 150 mg/l and a foul concentration of 600 mg/l, influent mass IM= 84960 mg/s and foul mass, FM = 56.64 l/s x 600 mg/l = 33984 mg/s. As before RR is 40% while E = 30%.

Example 4

A simplified version of removal rate determination using foul flow solids concentration is possible by defining a foul flow concentration factor, ffc, as the ratio of the foul flow concentration, F, to the influent concentration, I, that is, ffc = F/I. Removal rate is the foul flow concentration factor times the foul flow percentage, RR=ffc x FF

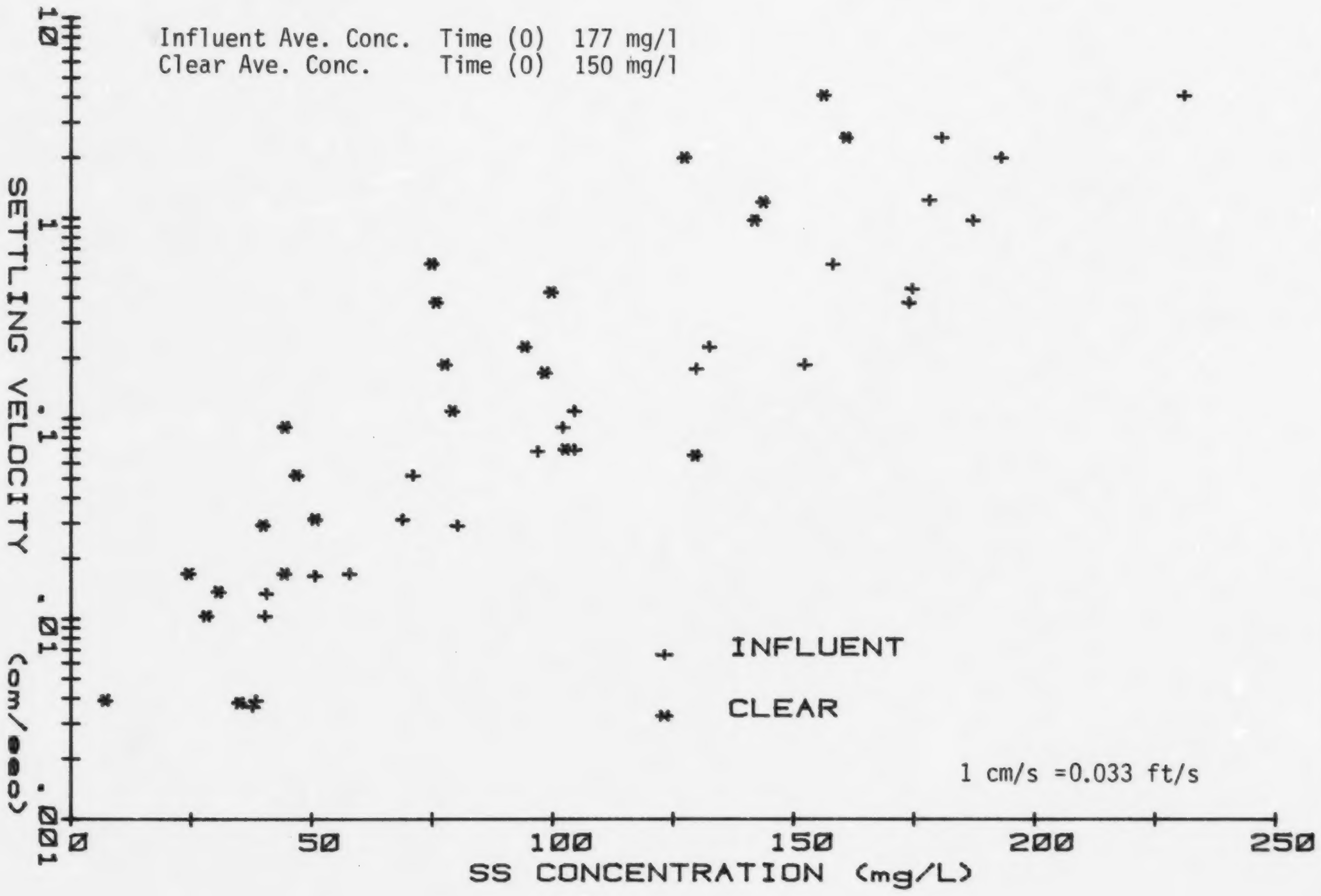
For the above data ffc = 600/150 =4
RR = 4 x 10 = 40%
and E is RR minus the percent foul flow or 30%

### 11.7 Settleability Curve Manipulations

The following two plots are examples of various graphical ways of presenting settling column results. The example used is for the storm event occurring in Lancaster on 7/2/81. Samples from the Swirl influent and clear were taken and settling column tests performed. Figure 75 displays the original data as concentration remaining as a function of settling velocity. Figure 76 is the standard plot of percent remaining as a function of settling velocity. This plot allows the determination of fractions of the material in the sample with settling velocities within a certain range.

In the case of efficiency evaluations of treatment processes, the efficiency (treatment removal) percentage is desireable for various settleability ranges. The standard removal plot requires that the change in percent remaining for each sample be determined over the chosen settling velocity range. These percentages must then be converted to a concentration basis, compared, and the removal percentage calculated.

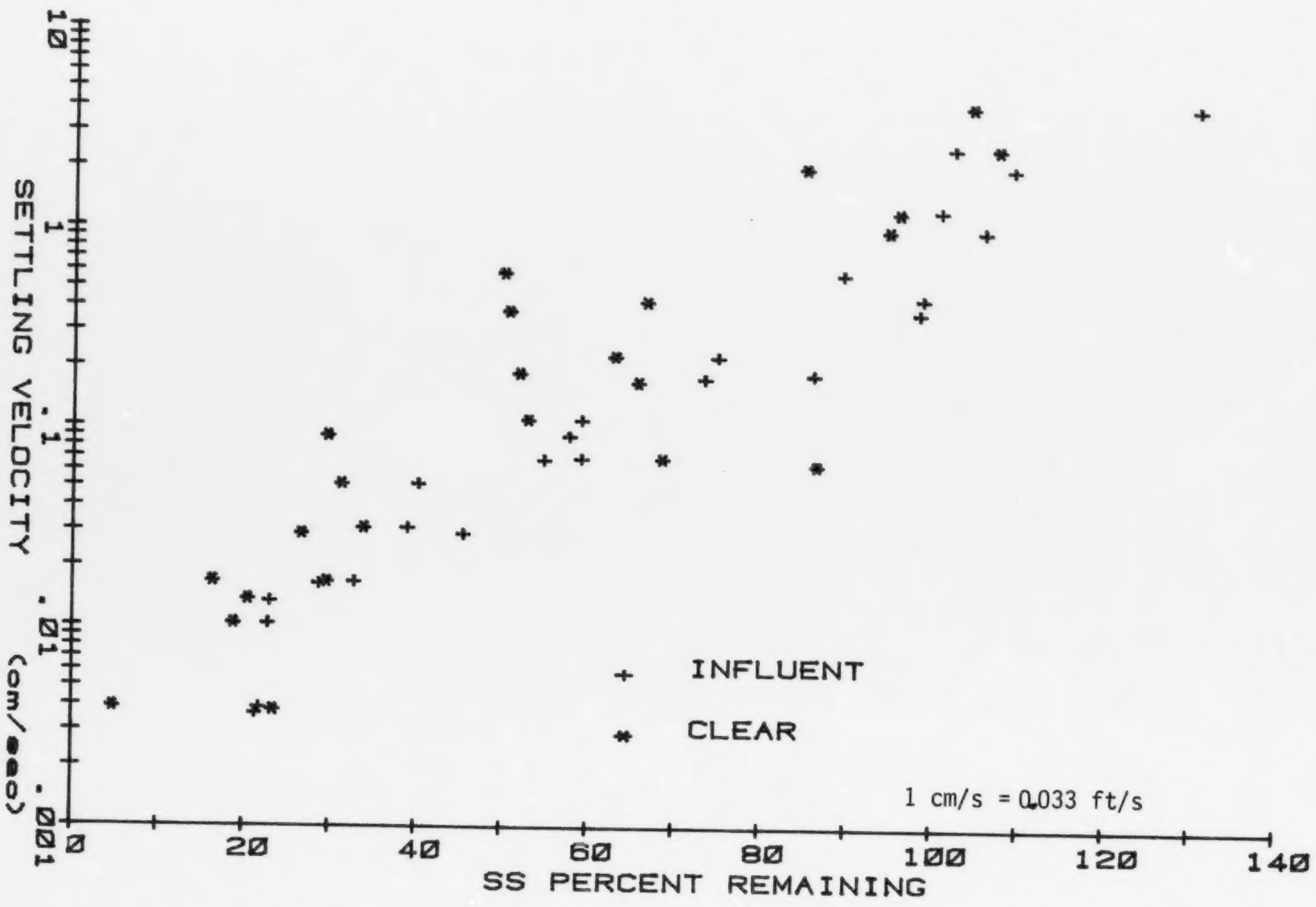
From Figure 76 the procedure is as follows: for a settling velocity range of 1.0 to 0.1 cm/sec (0.03 - 0.003 ft/s) the influent covers the range of 100% to 62%. This 38% difference corresponds to a change of 67 mg/l based on the initial influent concentration of 177 mg/l. The clear sample covers the range of 78% to 44% remaining, the difference of 34% corresponding to 51 mg/l based on the initial clear concentration of 150 mg/l. Determination of percent removal next requires subtracting the relative solids values in this range yielding 16 mg/l and then dividing by the influent concentration change within the range yielding 24% removal in the range or by the initial concentration to determine overall removal within this range, i.e. 16/177 or 9%.



Influent Ave. Conc. Time (0) 177 mg/l
Clear Ave. Conc. Time (0) 150 mg/l

1 cm/s =0.033 ft/s

Figure 75. Settling Column results, Lancaster (7/2/81).



1 cm/s = 0.033 ft/s

Figure 76. Suspended solids remaining vs settling velocity, Lancaster Swirl (7/2/81).

This lengthy process can be simplified by plotting the data with the clear % remaining values normalized to the initial influent concentration. All clear percentage valus are determined as mg/l remaining divided by the initial influent concentration.

The resulting plot is exhibited in Figure 77. The procedure for determining removals using this plot begins as before by determining % remaining changes over the desired settling velocity range. For the range between 1.0 and 0.1 cm/sec the values are 38% for the influent, as before, and (65-36) 29% for the clear. Since the values are normalized to the influent concentration the overall removal is simply the difference or 9% as before and the removal within the range is (9/38) 24%, also as previously found but much more easily determined. Normalized plots allow a significantly easier method of efficiency determination and were utilized for data review.

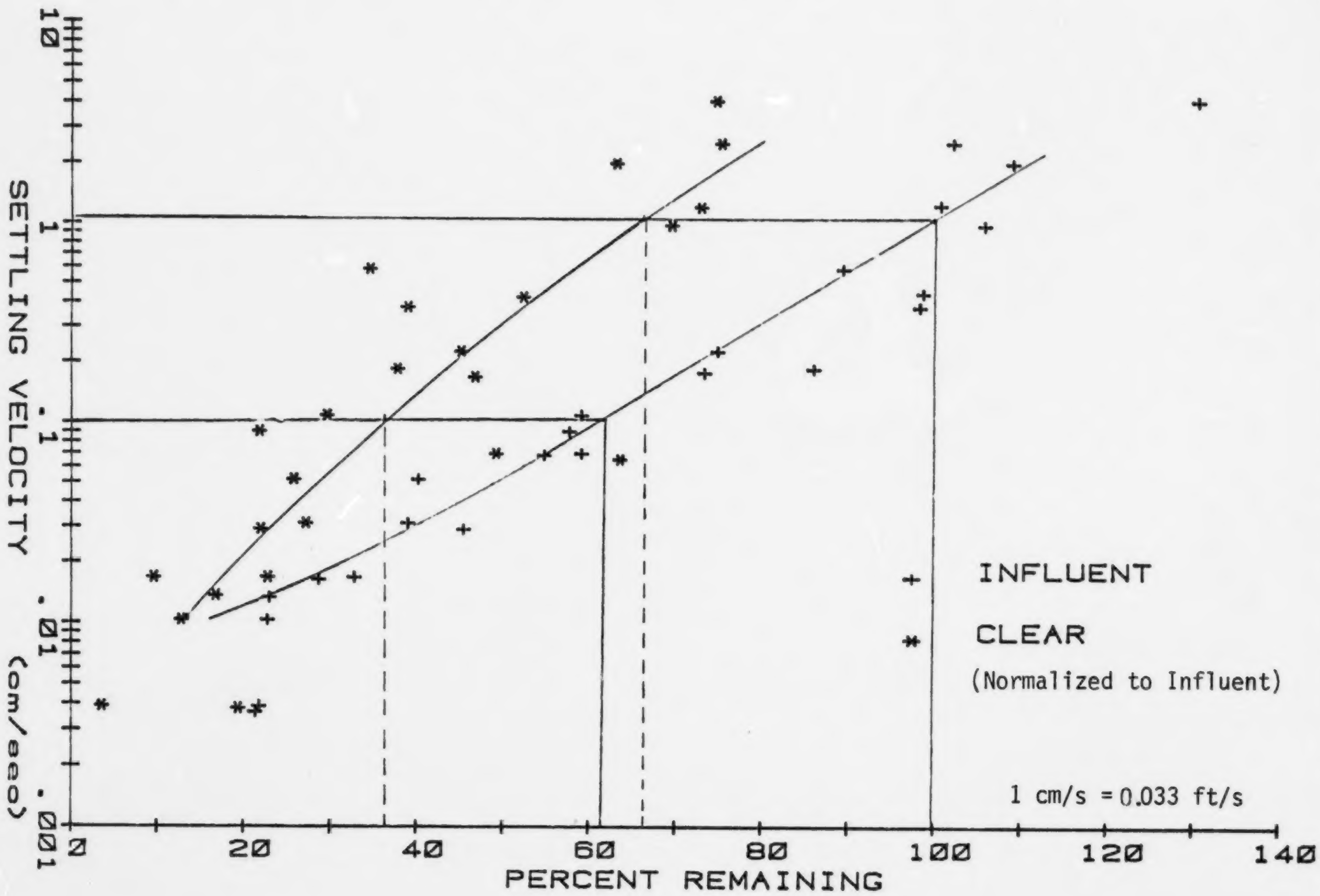


Figure 77. Normalized suspended solids remaining vs settling velocity, Lancaster Swirl (7/2/81).

# CHAPTER 12
# Lancaster Swirl Evaluation

## 12.1 Foreword

This chapter details the evaluation results of the Lancaster Swirl Regulator/Concentrator, Swirl Degritter and the Discostrainer. A chronology of events is presented in section 12.2. A short description of each sampling event during the EDP fall, 1980 to summer, 1981 evaluation program is given in section 12.3. A comparative assessment of Swirl Concentrator/Regulation influent suspended solids concentrations obtained for a number of storm events using the new EDP Technologies Cross Sectional sampler vs conventional application of Manning sampler is presented in section 12.4. These results indicate that early conclusions regarding poor performance of the Swirl facility during the 1979 period (pre EDP involvement) were incorrect. These comparative results also have a bearing on fall, 1980 evaluation program. The new samplers had not been installed as of this point. Detailed descriptions of a selected set of 1980-1981 sampling events are presented for the Swirl Concentrator/Regulation in section 12.5. The comparative influent sampler results are used in section 12.6. to reassess several storms where performance was seemingly poor. Ancillary Swirl Concentrator sampling results are presented in Section 12.7. Settleability results for the Swirl Concentrator are presented in section 12.8. An overview performance summary for the Swirl Concentrator is presented in section 12.9. Section 12.10 and 12.11 discuss the operation of the Swirl Degritter and Discostrainer respectively. The performance of the Hydro-Brake located on the Swirl foul sewer is discussed in Section 12.12.

## Section 12.2. Summary of Lancaster Evaluation

The following summary highlights the major activity during the evaluation program conducted by EDP.

| | |
|---|---|
| 1/11/80 | Swirl influent settleability experiment performed |
| 7/31/80 | Short storm event/operation/no sampling |
| 8/2/80 | Facility checked out and placed in automatic operation mode |

| | |
|---|---|
| 8/10/80 | Storm event sampled. Clear Swirl water sampler non-operational (manual sampling performed) |
| 8/30/80 | Light rain / no operation |
| 9/2/80 | Light rain / no operation |
| 9/10/80 | Storm event sampled |
| 9/14/80 | Storm event sampled |
| 10/2/80 | Storm event sampled |
| 10/21/80 | New EDP Technology samplers installed at site |
| 12/23/80 | Second level sensor for Swirl installed |
| 2/2/81 | Storm event / no operation |
| 2/4/81 | Site checked out. Non-operation of 2/2 event due to failure of Swirl level sensor |
| 2/9/81 | Swirl Level sensor removed and sent to manufacturer |
| 3/9/81 | Swirl Level sensor returned |
| 3/12/81 | Swirl Level sensor re-installed, all set for next storm. |
| 4/1/81 | Storm event sampled/sampler problems |
| 4/2/81 | Dye study equipment arrived |
| 4/14/81 | Light rain/ no sampling |
| 4/22-23/81 | Visit by EDP to adjust samplers and set up dye calibration equipment. Discovered problems with Swirl level sensor explaining results of 4/1 event |
| 4/27/81 | Light rain/no samples |
| 4/29/81 | Level sensor adjusted |
| 5/6-7/81 | Visit by EDP personnel to adjust samplers. Found electronic controls burnt-out and heavy solids blocking EDP sampler feed lines. |
| 5/10/81 | Storm event sampled<br>EDP influent sampler plugged<br>EDP foul sampler partial plugged |

| | |
|---|---|
| | Clear sampler not operational/no samples<br>Doppler meter not operational |
| 5/15/81 | Light rain/ no samples/ Mapco meter observed |
| 5/27/81 | Backwash system recommended by EDP on 5/7<br>Installed on Swirl Degritter<br>Doppler meter recalibrated<br>Site operator called Mapco with 5/15 results |
| 6/1/81 | Mapco reports no idea as to cause of problems |
| 6/2/81 | Storm Event - sampled<br>EDP influent sampler clogged/ no samples<br>EDP foul sampler functioned correctly<br>Manning Clear samples 8 empty-low flow reported<br>Doppler unit not operational |
| 6/17/81 | EDP calls Mapco and L&N about flow meters |
| 6/19/81 | L&N rep. at site to repair motor |
| 6/22/81 | New Operator prepares site for event<br>Storm event<br>EDP samplers worked well<br>Manning clear sampler malfunctions |
| 6/25/81 | EDP conversation with Mapco rep/ repair requisition given to Mapco. |
| 7/1/81 | Storm event sampled Swirl Degritter inoperative |
| 7/20/81 | Two storm events sampled. Basement flooded during first storm "shorting" Degritter sampler |
| 7/28/81 | Storm event sampled for only settleability characteristics |

## Section 12.3. Description of Each Sampling Event

The following section includes an overview summary of each sampling event and analysis data. Performance data is briefly described. The four events monitored in 1980 occurred after instituting the first set of instrumentation changes EDP recommended after observing the cross-site in 1979. The second set of changes, that is, new EDP Technologies Cross-Sectional samplers were installed in early 1981. A detailed discussion of a selected set of events is included in section 12.5.

## Lancaster Swirl 8/10/80 Storm Event Summary

The first storm event monitored after the facility was shutdown in early 1980 ocurred on 8/10/80. The storm was characterized by a moderate thunder shower followed by steady light rain. The antecedent period was hot and dry for about one week.

Samples were collected at four locations during the event including the Swirl influent, clear effluent and the foul effluent (which acted as the Degritter influent) and at the degritter effluent. All samples were tested for TSS, VSS, settleable solids, volatile settleable solids, ammonia, COD and TOC.

Results indicated clear overflow concentrations to be much higher than those from any other sampling station, indicating that accumulation of materials within the sampler intake and intake line had occurred during facility shut down period. This possibility led to the standard procedure of rinsing all equipment routinely and prior to pending storm events. Available data was insufficient to perform conclusive performance analysis.

## Lancaster Swirl 9/10/80 Storm Event /Summary

The storm event was characterized by moderate showers lasting 45 minutes with a total accumulation of 0.18 in. (0.45 cm) of rain. The antecedent dry period was 10 days.

Liquid samples were collected at four locations (as in 8/10/80) during the event, and one sample was taken from the grit hopper. A total of 23 liquid samples were collected at 7.5 minute intervals.

Although there were problems with the flow meters, flow record analyses indicate influent flow to have been approximately 18 cfs (509.76 l/s) at the start of the storm and drop to 1 cfs (28.3 l/s) by the end of sampling, with 1.2 cfs (34 l/s) flowing to the Degritter.

All liquid samples were tested for TSS, VSS, settleable solids, volatile settleable solids, ammonia, TOC and COD. The grit sample was tested for volatile content. Results indicate good removals within the Swirl unit. Details are included in section 12.3.

## Lancaster Swirl 9/14/80 Storm Event Summary

The storm event consisted of a brief heavy shower lasting only 30 minutes with a total accumulation of 0.26 in. (0.66 cm) of rain. The antecedent dry period was 3 days. Influent flow rates ranged from 40 to 6 cfs (1133 to 170 l/s) during a 30 minute evaluation period. Liquid samples were collected at four locations (as in 8/10/80) during the event and two samples were taken from the grit hopper. A total of 20 liquid samples were collected at 7.5 minute intervals. Difficulties continued with the influent meters and weir overflow rates were used to estimate flow volumes.

All liquid samples were tested for TSS, VSS settleable solids and volatile settleable solids. Grit samples were tested for volatile content. Results indicate a much higher solids concentration in the first clear overflow sample than within the influent or foul flows. It is hypothesized that the first flush effect resulted in a large amount of floatables being introduced to the unit. This material would rise to the unit surface and not be included as part of the foul flow or samples. As the unit fills, these floatables would accumulate on the surface and be released with the first clear overflow in a concentration higher than the influent level. Unfortunately, no visual observations were made during the storm and this phenomenon could not be documented.

Unlike the storm event of 8/10/80 a very short time had passed since the sample unit was last utilized limiting the likelihood of accumulations buildup in the sampler intake and intake line as assumed for the 8/10/80 event.

Solids concentrations in the remaining clear samples indicate Swirl Concentrator removal rates of about 30% at inflow rates near 20 cfs (566.4 l/s) diminishing to minimal removals at later flow rates of 10 cfs (283.2 l/s) and less. As with the 9/10/80 event this is probably due to the solids characteristics change during the event rather than being related to flow rate. Additional Swirl discussion of this event is included in section 12.3. The Swirl Degritter performance during this event is detailed in section 12.10.

## Lancaster Swirl 10/2/80 Storm Event Summary

The storm event was characterized by three distinct downpours resulting in 0.02 in. (0.05 cm), 0.08 in. (0.2 cm) and 0.20 in. (0.5 cm) of rain, respectively. The antecedent dry period was one week.

Sampling began during the first rain period and continued through the second and third downpours. The first downpour lasted about 5 minutes, followed one hour later by a second event lasting about 10 minutes and after 15 more minutes the heaviest rain fell over a 30 minute period. A total of 46 liquid samples were collected and 2 grit samples were taken. Due to the intermittent nature of the storm the sample collection intervals were irregular. Samples were tested for TSS, VSS, settleable solids, volatile settleable solids and COD. Grit samples were tested for volatile content. Results indicate good removals during the event. Swirl details are included in section 12.3.

### Lancaster Swirl 4/1/81 Storm Event Summary

The storm event was characterized by two distinct downpours. The first downpour lasted 75 minutes and resulted in an accumulation of 0.26 in. (0.66 cm). The second occurred 45 minutes later, lasted 1 hour and resulted in an accumulation of 0.23 in. (0.58 cm). Combined with periods of drizzle the total accumulation during the event was 0.58 in. (1.47 cm). The antecedent period included a rainfall accumulation of 0.25 in. (0.635 cm) over a 6 hour period during the day prior to the evaluated event preceded by 13 dry days.

Sampling began during the first downpour and continued for 2 hours. Samples were collected using the EDP Swirl influent sampler, the Manning Swirl influent sampler, and the Manning clear overflow sampler. Failure of the EDP foul sampler to produce samples was later found to be due to debris clogging the discharge mechanism. Observations of the EDP influent sampler operation after the first samples had been obtained showed that samples were possibly contaminated by intermixing and no analysis was performed. (Later review of the actual sampling operation indicated that the unit operated properly). No grit samples were collected and no indication of grit weight increase was recorded on the charts. Both the Mapco and the Leeds and Northrup influent flow meters operated during this event, however, the Mapco unit failed to operate during the first 15 minutes. This was the first event during which the Doppler flow meter operated.

All past events have demonstrated the trend of pollutant concentrations being initially high, dropping quickly and then tapering off. During this event, flow rates were recorded for the first time over the initial 15 minute period. Review of the data obtained from analysis of initial samples collected by the EDP Technologies swirl influent sampler before "inter-mixing" indicates a "first flush" effect.

4/1/81 Storm Data

Analysis of First 30 Minutes of Event

1 cfs = 28.3 l/s

| TIME MIN. | FLOW cfs | INF. SUSPENDED SOLIDS mg/l | MASS FLOW RATE grams/sec |
|---|---|---|---|
| 7.5 | 66.2 | 1439.8 | 2697 |
| 15 | 68.2 | 861.3 | 1662 |
| 22.5 | 53.6 | 650.7 | 987 |
| 30 | 50.5 | 522.0 | 746 |

Analysis of this storm is not included in section 12.3 due to the uncertain nature of the Swirl influent sampling.

## Lancaster Swirl 5/10/81 Storm Event Summary

The storm event was characterized by light rain over a three hour period with an accumulation of 0.03 in. (0.08 cm) followed by one hour of moderate rain and 0.11 in. (0.28 cm) accumulation. The antecedent period had been dry for eight days.

The Swirl operation commenced and sampling was performed during the moderate rain period. Samples were collected using the Manning Swirl influent sampler, the EDP Swirl foul flow sampler, and the Manning degritter foul flow sampler. In addition, the Swirl tank was sampled at the end of clear overflow to define tank concentrations. The EDP Swirl influent sampler clogged after collection of the first sample The backflush system had not yet been installed to alleviate the problem. Manning sampler influent samples were therefore used during the analysis. At the time of the event the Manning clear sampler was not operational and no clear samples were collected. Neither the Mapco or Doppler influent meters operated properly limiting the influent data.

Based on these irregularities the number of samples selected for final analysis was limited to five influent, eight Swirl foul, five Degritter foul, and six Swirl tank samples.

The eight Swirl foul samples consisted of four sample pairs intended to demonstrate the variability of sample collection. Samples were analyzed for TSS, VSS, settleable solids and volatile settleable solids. Swirl details are given in section 12.3.

## Lancaster Swirl 6/2/81 Storm Event Summary

The on-site rain gage was not functional during this event. Local reports of the total rainfall accumulation during the 12 hour period was 0.80 in. (2 cm). The storm was not considered intense in nature.

All samplers simultaneously operated as the Swirl chamber began to fill. Samples were collected using the Manning Swirl influent sampler, the EDP Swirl influent sampler, the EDP Swirl foul flow sampler and the Manning Degritter clear flow sampler. The EDP Swirl influent sampler became plugged after the initial sample was taken and did not become operational again until the latter half of the storm. Manning Swirl influent samples were used for initial influent analysis.

During the event the clear overflow receded below the weir level mid-way through the storm resulting in several empty clear sample bottles.

The Mapco flowmeter was not operational until approximately 11 minutes into the storm. The Doppler flowmeter failed to operate. Samples selected for final analysis included twelve influent, three clear, seven swirl foul and two degritter foul. Samples were analyzed for TSS, VSS, settleable solids and volatile settleable solids.

Visual observations following the storm event include, approximately three buckets of leaves, paper and a few cans remained on barscreen, very little debris on either the Swirl or Degritter weirs and little grit accumulation from the Swirl Degritter.

Removal data is limited due to the lack of clear samples and influent samples from the EDP Swirl sampler. No conclusions were drawn from this event.

## Lancaster 6/22/81 Storm Event Summary

The antecedent dry period prior to this event was 15 hours. Two days before the event the area received 0.25 in. (0.64 cm) of low intensity/drizzle precipitation. Prior to this the antecedent dry period was 5 days. The storm was intense in nature filling and overflowing the Swirl almost instantly. Samples were collected using the Manning Swirl influent sampler, the EDP Swirl influent sampler, the EDP Swirl foul flow sampler and the Manning Degritter foul flow sampler. Grab samples were collected.

All samplers except the Swirl clear overflow worked properly during this event. Samples selected for final analysis included 18 Swirl influent samples (12 EDP and 6 Manning), 1 Swirl clear, 12 Swirl foul, 12 Degritter foul and 6 Swirl tank samples. Analyses included total settleable solids, volatile settleable solids and COD. Results of this event included a dramatic comparison of the Manning sampling and the new EDP device as discussed in section 12.4. Removals within the Degritter are included in section 12.10.

### Lancaster Swirl 7/2/81 Storm Event Summary

This event was characterized by an intense rain which lasted 70 minutes during which nearly 2 in. (5.1 cm) of rain accumulated. Automatic initiation of the sampling system began with the first clear overflow occuring several minutes later. Since personnel were on-site awaiting the event, manual sampling for settleability analysis commenced simultaneously with this initial overflow so as to catch the "first - flush" effect. Settleability sampling required about 15 minutes after which time routine site evaluation and the specialized dye injection flow calibration system was operated.

Samples were collected using the EDP Swirl influent sampler, the Manning Swirl clear sampler, the Manning Degritter clear sampler and the EDP Swirl foul sampler. Swirl foul samples were limited due to operational problems. In addition, Swirl tank samples were collected twice during the operation and a background dry weather flow sample collected just prior to the event. Results indicated good removals and are included in section 12.3.

### Lancaster Swirl 7/20/81 Storm Event Summary

On July 20 two storm events occured. The first began at 5:45 am, lasted about forty minutes and resulted in 0.18 in. (0.45 cm) of rain. The second event began at 6.55 pm, lasted about fifteen minutes and amounted to 0.35 in. (0.89 cm).

During the first event the Swirl Degritter and Discostrainer were operated and settleability samples were collected from the Swirl influent and clear flows. A problem with the valving system in the building basement caused the Degritter to overflow and partially flood the basement. As a result the settleability samples were collected some time after initial activation of the site, discrete samples were minimal, and the EDP foul sampler located near the basement floor was flooded and"shorted-out."

The second event occured less than 12 hours later. Since it had been dry for 16 days prior to the morning event and since the morning event was only of mild intensity the evening event (predicted to have heavy rainfall) was also monitored.

All samplers operated properly during this event with the exception of the EDP foul sampler which had been flooded in the morning storm. Settleability samples were collected for Swirl influent and clear and from the Degritter influent and clear overflow.

Results of the morning event were limited and no conclusions were formulated. Settleability, degritter and discostrainer results are discussed in sections 12.8, 12.10 and 12.11, respectively. Results of the evening event discrete sampling demonstrated good removals and are included in section 12.3. Settleability samples indicated poor removals.

### Lancaster Swirl 7/28/81 Storm Event Summary

Based on the poor settleability data from the 7/20/81 event it was decided to test again the Swirl influent and clear flow settleability characteristics. For this final event, collection of samples at the very start of the storm was stated as the main priority with all other activities of secondary importance. Influent samples were collected in the diversion chamber. The flow-through apparatus with slide gate closures was used for 12 gal (45.4 l) of sample from the diversion chamber at which point the device malfunctioned. The remaining 20 gallons (75.7 l) of sample were taken via the 3 in. (7.6 cm) influent line tap in the building. Influent samples were also collected with the EDP Swirl influent sampler for comparative analysis. Results again indicated poor removals as discussed in section 12.8.

## 12.4. Comparison of Swirl Influent Concentrations Using the Manning 6000 unit and the EDP Technologies Cross Sectional Sampler.

During four of the events monitored in 1981 a total of fourteen simultaneous, or near simultaneous influent swirl samples were collected using the 36 in. (91.8 cm) EDP Technologies, Inc. Cross-Sectional Sampler and the Manning sampler. Suspended, volatile suspended, settleable and volatile settleable solids analysis were performed on each sample.

Relative concentrations of each of these parameters were compared for simultaneous samples. For near simultaneous samples time-weighted average concentrations were used for comparison.

In all cases solids within samples from the Cross-Sectional sampler unit were substantially higher than those from the Manning sampler. Influent data from the 6/22/81 event are plotted in Figure 78. Higher concentrations are illustrated at all times in the EDP influent. The ratio of relative suspended solids concentrations ranged from 6.7:1 to 2.2:1, and in general decreased with time of operation. A single clear sample was collected during this event and is obvious that whereas the Manning influent sample concentration implies no removal the samples obtained by the Cross-Sectional sampler implies good unit performance. This concept is further considered at the end of section 12.6.

Relative ratios of Swirl influent concentrations obtained by Cross-Sectional sample to Manning sampler ranged from 2.1:1 to 7.6:1 for the four events for suspended solids, with similar ranges for other solids types. These multipliers roughly relate to periods within the storm event as shown in Figure 79. During the first 10 minutes of an event suspended solids concentrations of samples collected with the Cross-Sectional sampler had typically 6 to 7.6 times the suspended solids concentration noted in samples taken with the Manning unit. Between 10 and 20 minutes of operation these ratios ranged from 4 to 1 up to 6 to 1. After 20 minutes of operation the effectiveness of the EDP sampler yielded about twice the solids concentration of the Manning unit.

These corrective factors were applied to two storm events to place into perspective seemingly poor Swirl efficiency performance results. For this purpose one storm was selected just prior to installation of the new sampler (fall 1980) and the other event prior to EDP involvement (1978). Results of these correction factor applications are provided in section 12.6. In both cases results indicate removals where previously the data appeared poor and inconclusive.

## 12.5 Detailed Event Analysis - Swirl Concentrator

Five storm event data sets were selected for detailed analysis and are presented in this section. These events were selected to demonstrate the efficiency of the devices or to illustrate other informative phenomema. These events include, in the order of review; 9/10/80, 10/2/80, 5/10/81, 7/2/81 and 7/20/81.

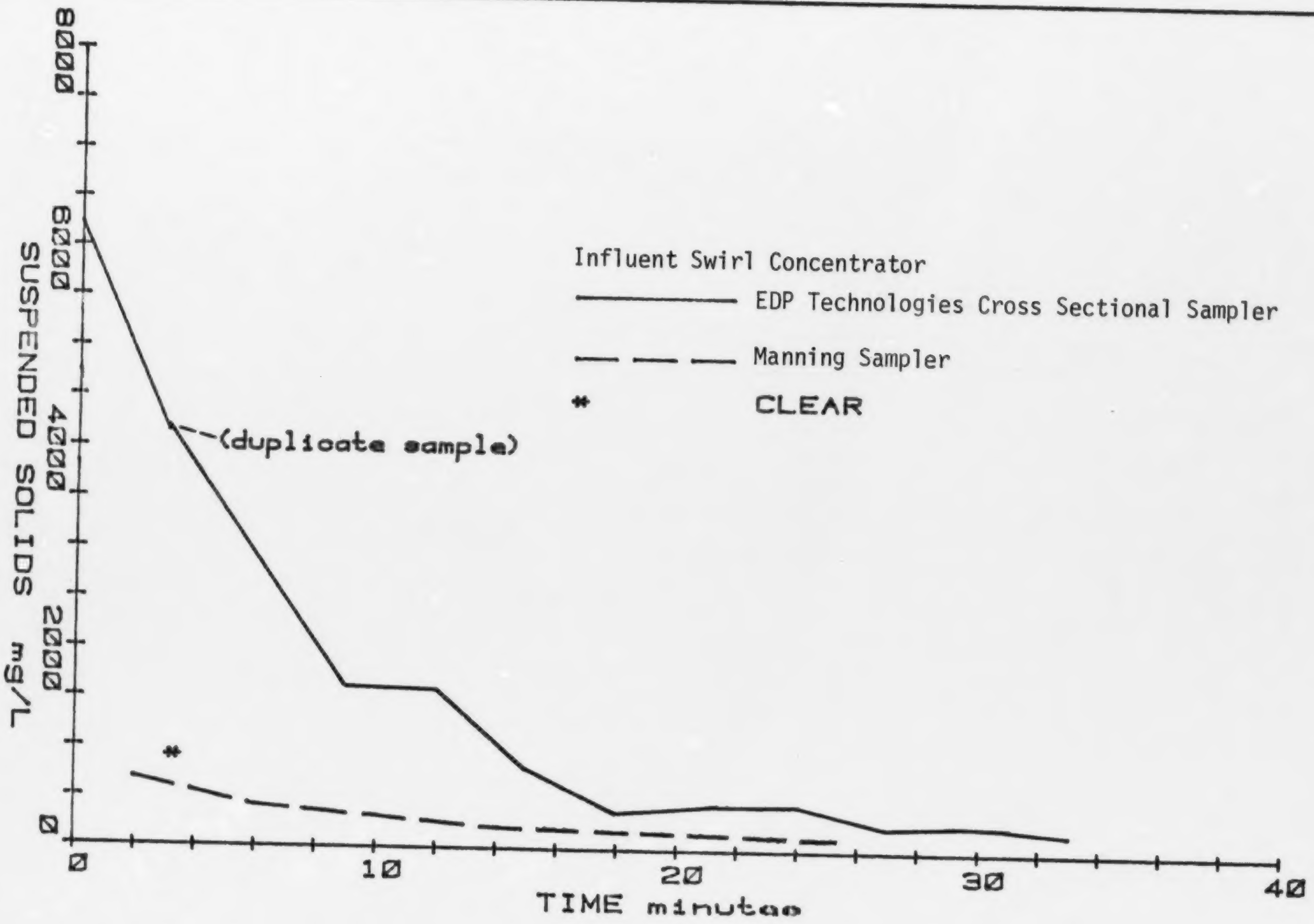


Figure 78. Suspended solids concentration vs time, Lancaster Swirl (6/22/81).

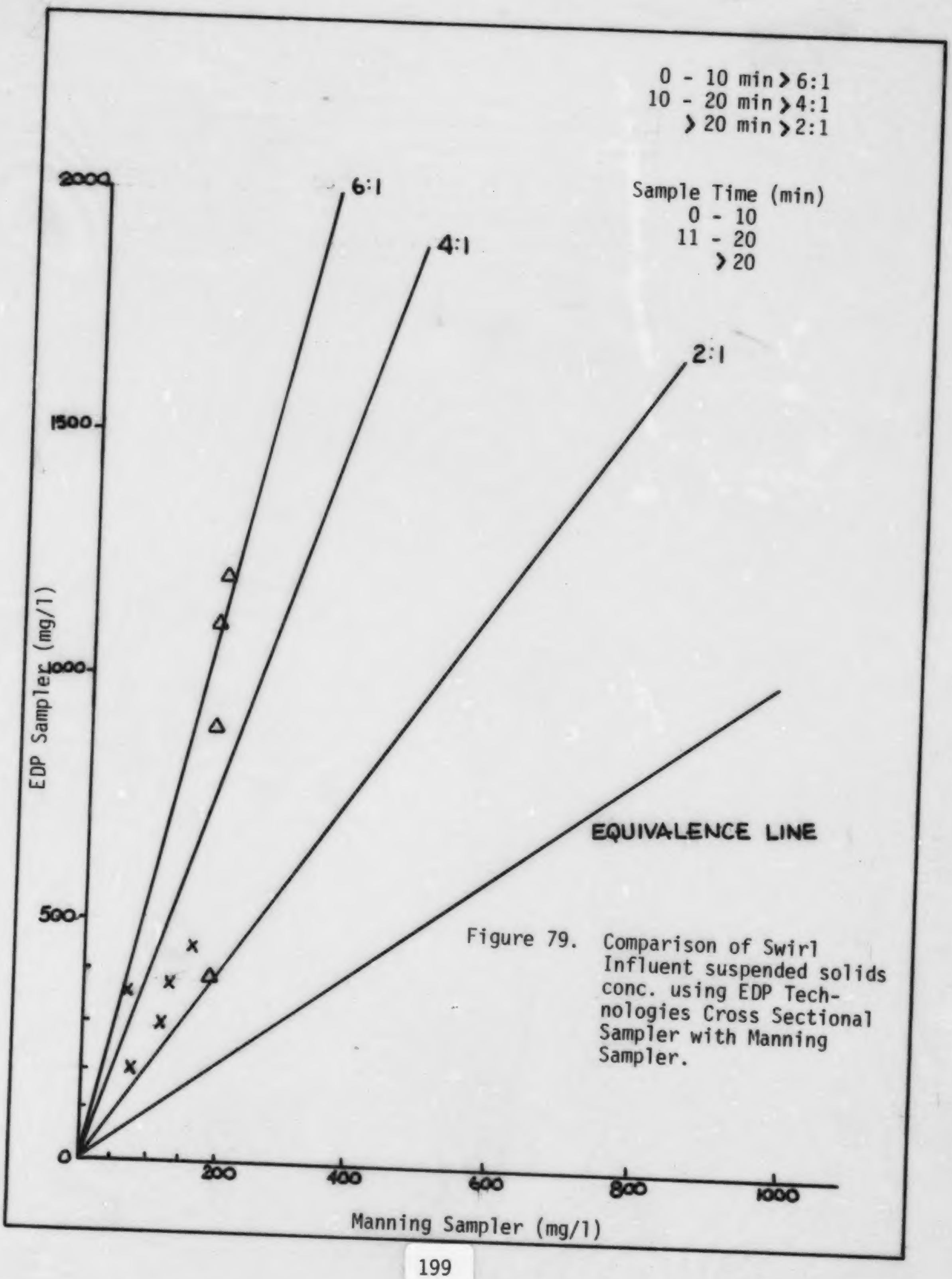


Figure 79. Comparison of Swirl Influent suspended solids conc. using EDP Technologies Cross Sectional Sampler with Manning Sampler.

## Summary of Results 9/10/80

Plots of suspended solids vs time shown on Figure 80 indicate good removal efficiencies for the Swirl unit. Clear effluent samples concentrations are substantially lower than influent levels indicating better than 30% removal throughout the storm. The initial clear sample was taken prior to operation of other sampling units since the unit began operation at the first electrical impulse whereas the other units are delayed by the sampling interval time. Based on influent vs clear overflow concentrations analysis, the greatest removal efficiency occured during the beginning of the event when both influent flow rate and influent pollutant concentrations were highest. During the Swirl operation suspended solids concentration fell from above 2000 mg/l to less than 200 mg/l. At the same time the clear overflow concentrations ranged from 600 mg/l to about 100 mg/l. Approximate flow rates were 18 cfs (509.7 l/s) for 20 minutes, 7 cfs (198 l/s) for the next 10 minutes and 1 cfs (28.3 l/s) for the remainder of the monitoring event.

Assuming an influent of 18 cfs (509.7 l/s) at the start of the event, 94% of the flow passed as clear effluent and contained only 27% of the original solids content. By the end of clear sampling, influent flow was about 6.5 cfs (184 l/s) the clear overflow accounted for 83% of the flow and contained only 53% of the solids content. The removal rate and efficiency at 18 cfs (509.7 l/s) were calculated to be 70% and 64%, respectively. At 7 cfs (198 l/s) the respective values were 50% and 39%. Although this indicates better performance at the higher flow rates, the results are most likely due to the greater amounts of grit during the "first-flush" period. All parameters exhibited trends similar to those exhibited by suspended solids.

Swirl Concentrator influent, clear and foul concentration vs time plots of volatile suspended solids, settleable solids and volatile settleable solids are presented in Figures 81 through 83, respectively. Swirl Concentrator influent, clear and foul mass vs time plots of suspended solids, volatile suspended solids, settleable solids and volatile settleable solids are presented in Figures 84 through 87, respectively. Inspection of these plots indicates that approximately 65% of the influent solids mass is settleable inorganic grit.

Using approximate flow rates, mass determinations indicate that at no time during the event would the effluent solids equal the influent mass flow implying solids build-up within the tank. At the Lancaster facility, there was no provision available for monitoring the complete event up to and including the final draw-down.

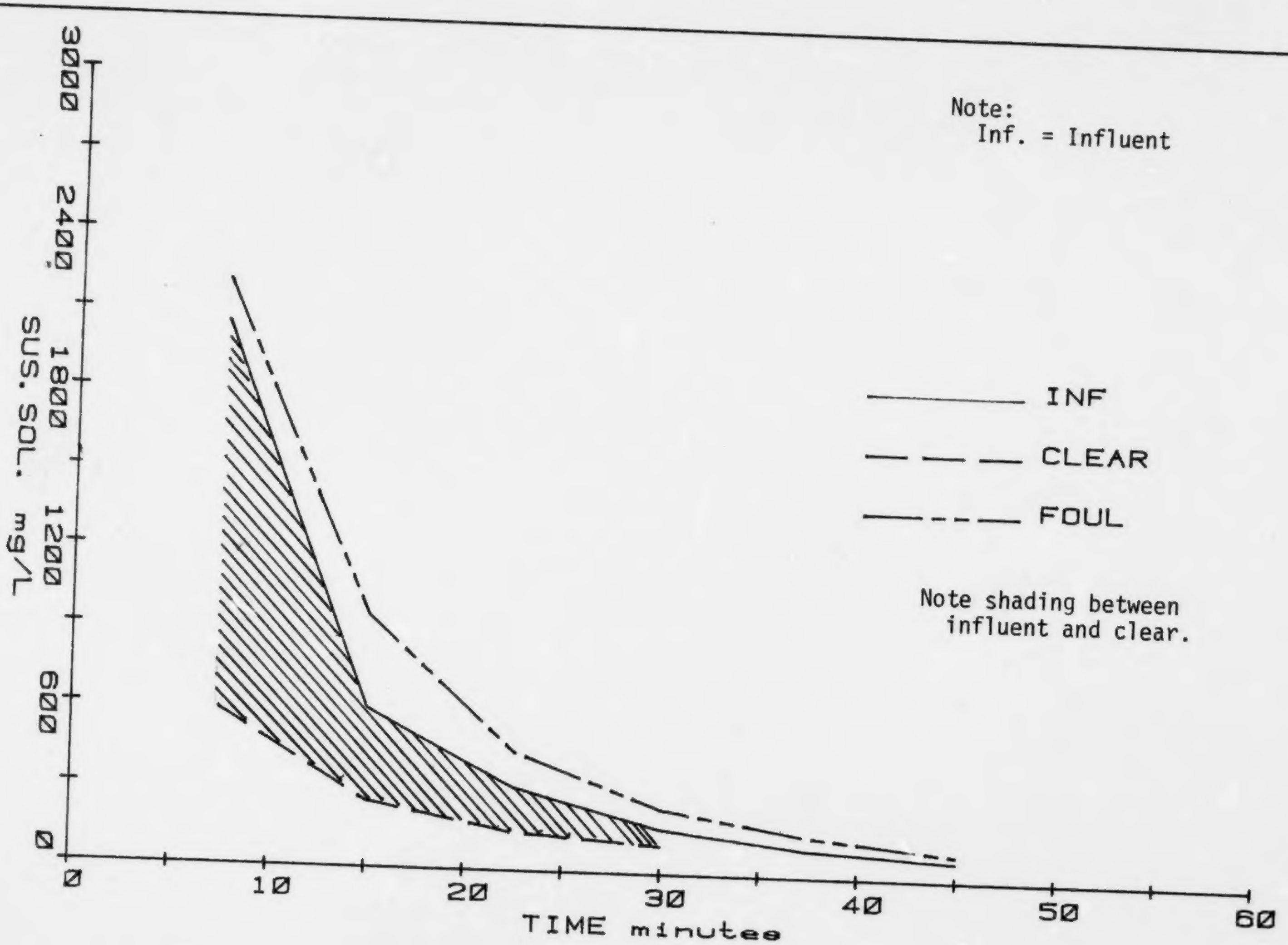


Figure 80. Suspended solids conc. vs time, Lancaster Swirl Concentrator/Regulator (9/10/80).

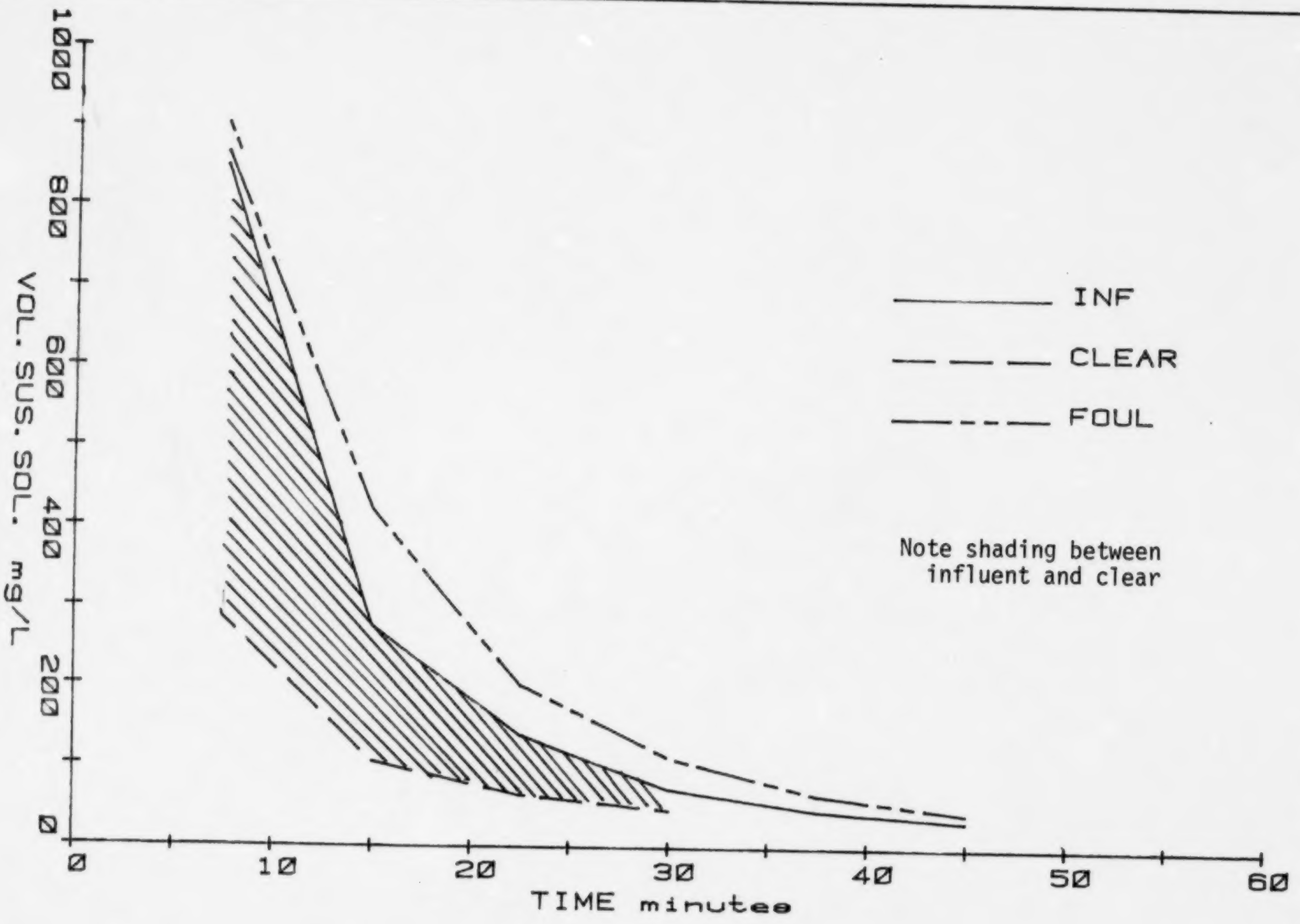


Figure 81. Volatile suspended solids conc. vs time, Lancaster Swirl Concentrator/Regulator (9/10/80).

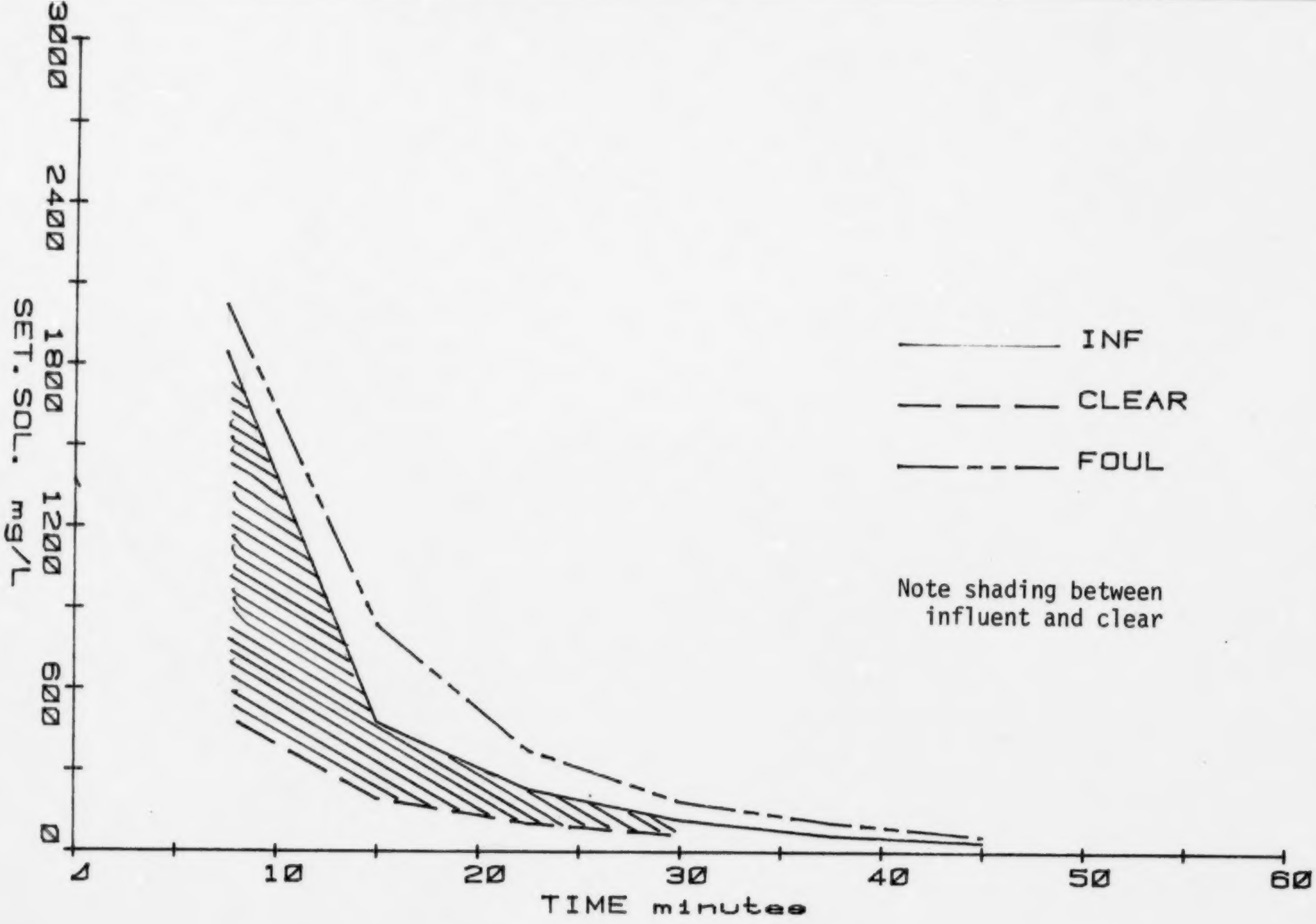


Figure 82. Settleable solids conc. vs time, Lancaster Swirl Concentrator/Regulator (9/10/80).

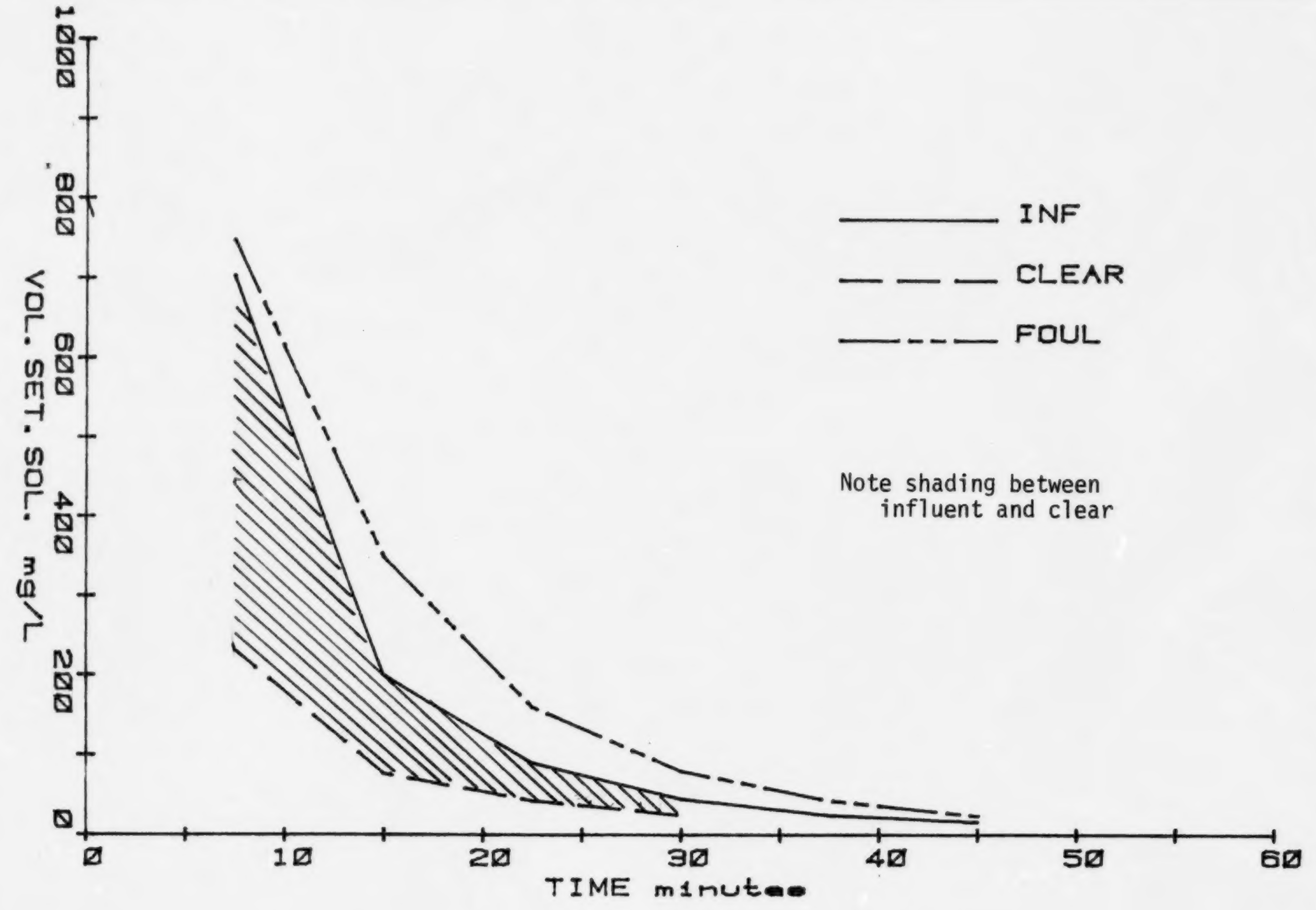


Figure 83. Volatile settleable solids conc. vs time, Lancaster Swirl Concentrator/Regulator (9/10/80).

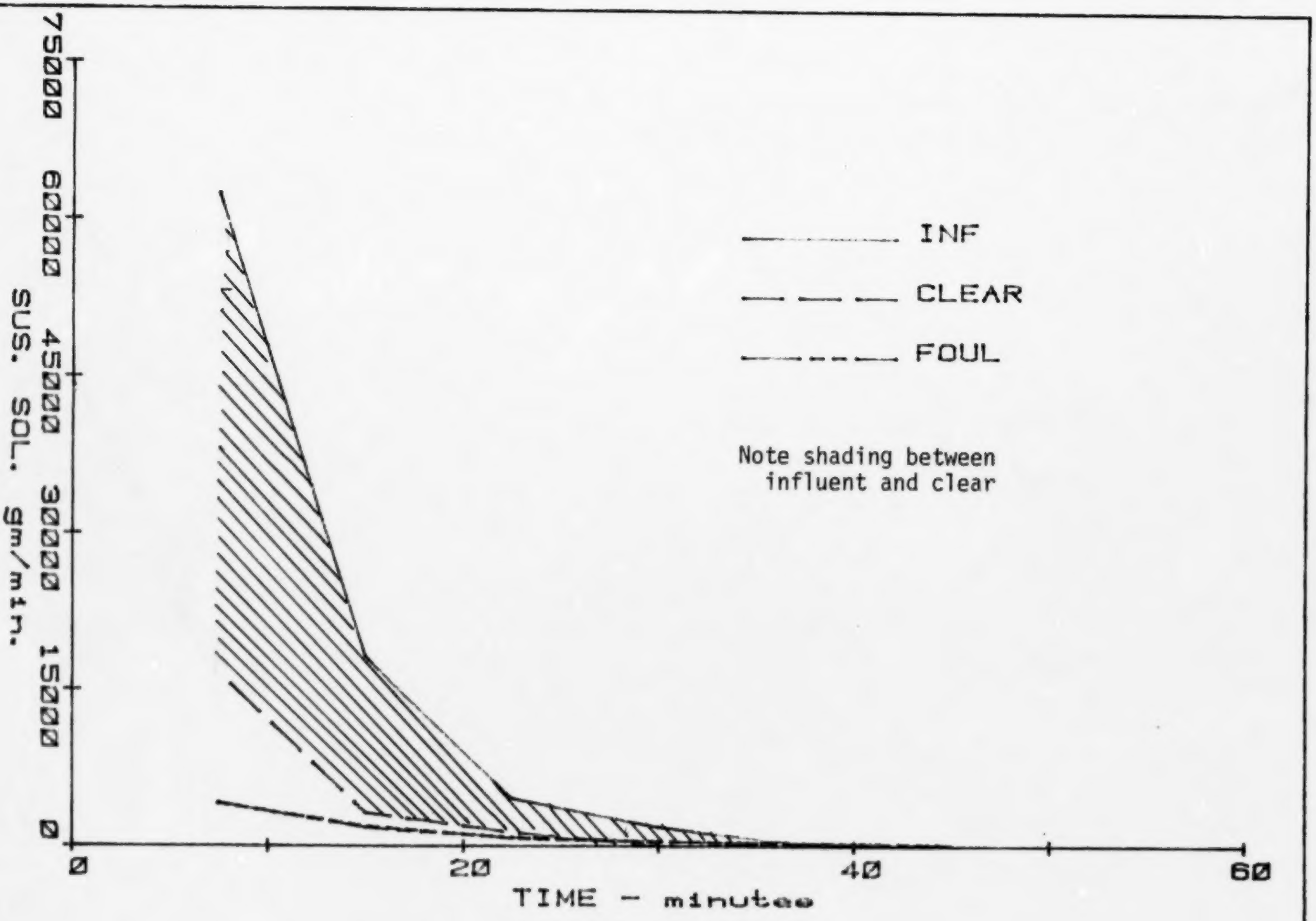


Figure 84. Suspended solids mass vs time,Lancaster Swirl Concentrator/Regulator (9/10/80).

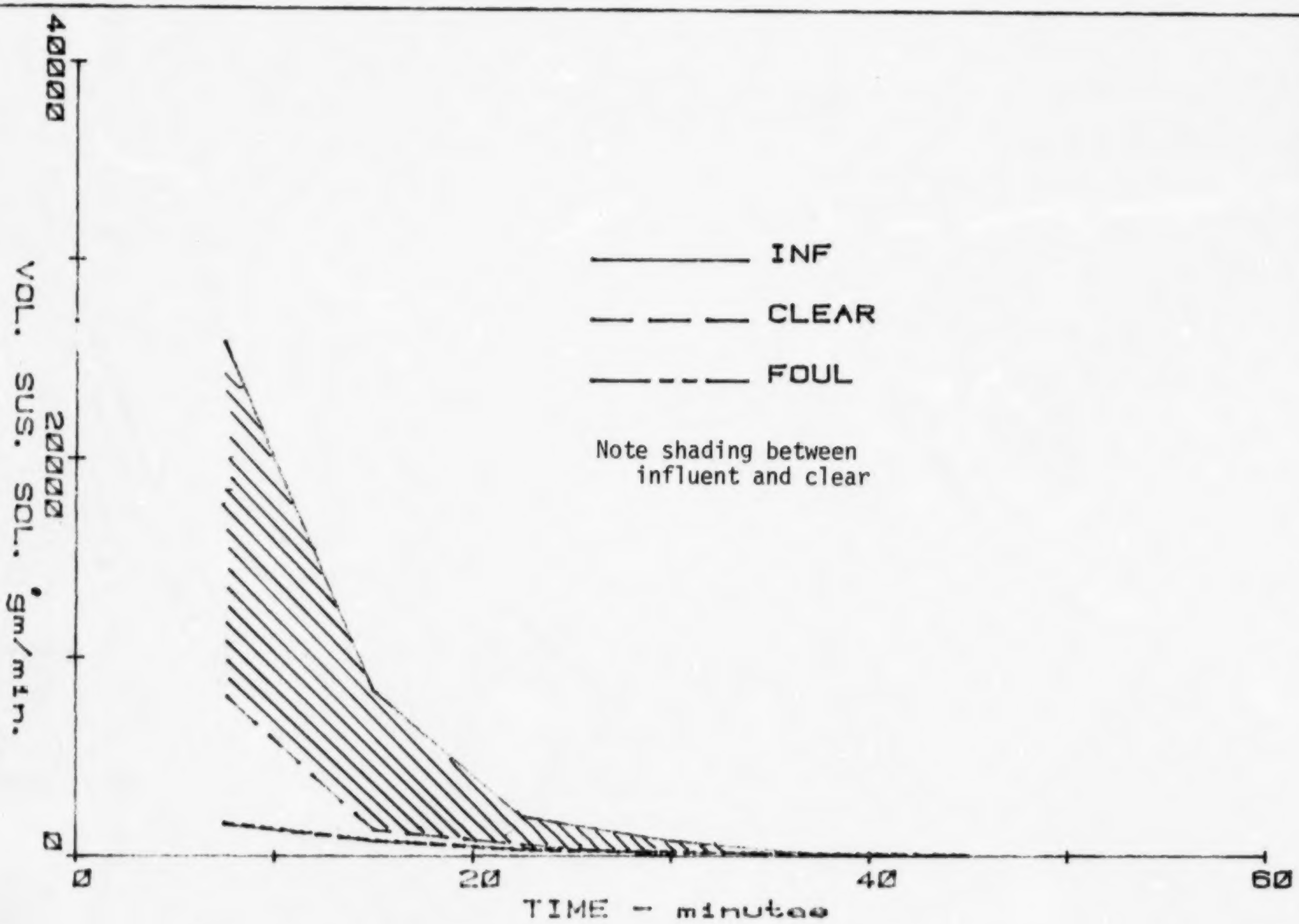


Figure 85. Volatile suspended solids mass vs time, Lancaster Swirl Concentrator/Regulator (9/10/80).

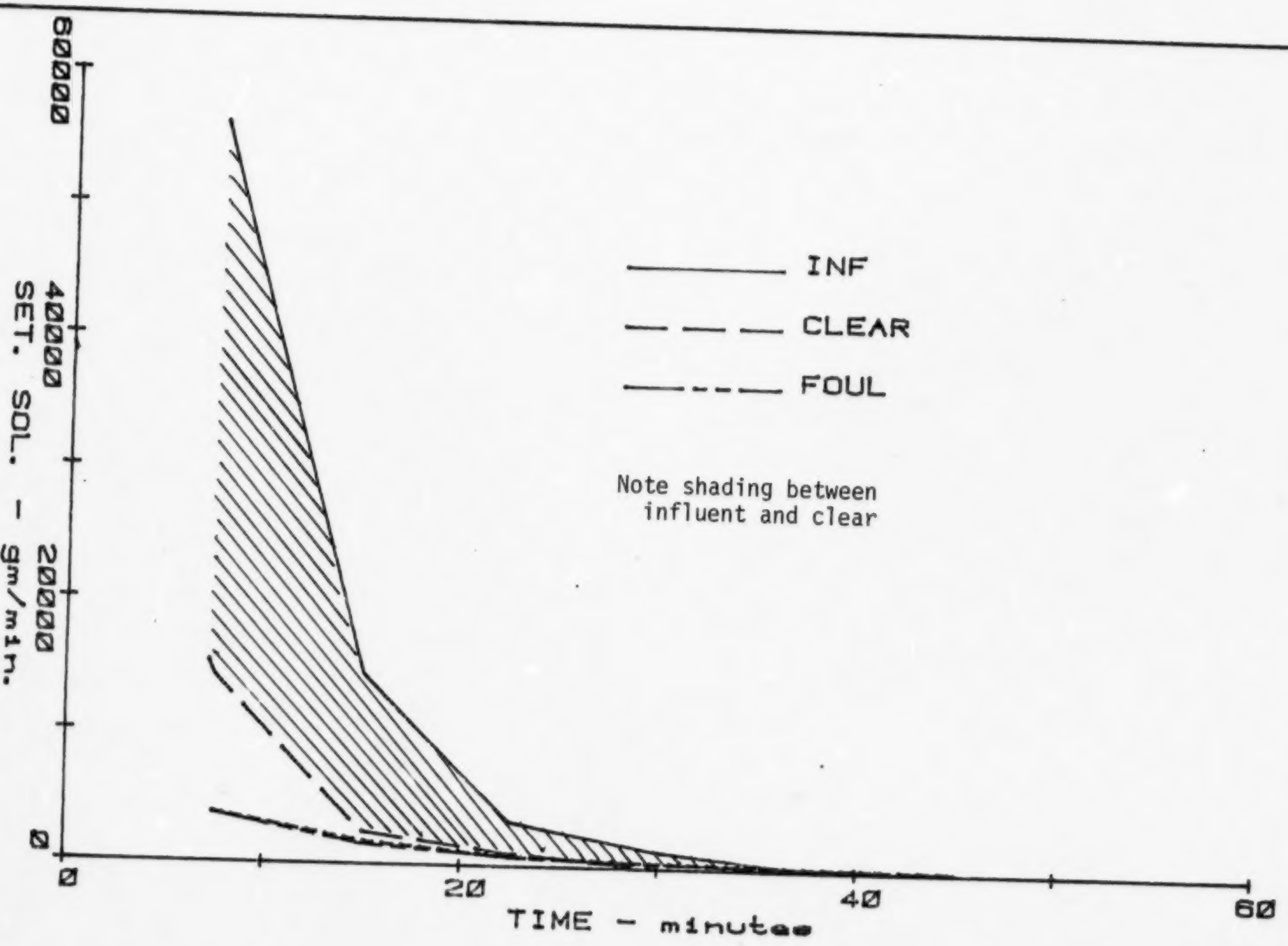


Figure 86. Settleable solids mass vs time, Lancaster Swirl Concentrator/Regulator (9/10/80).

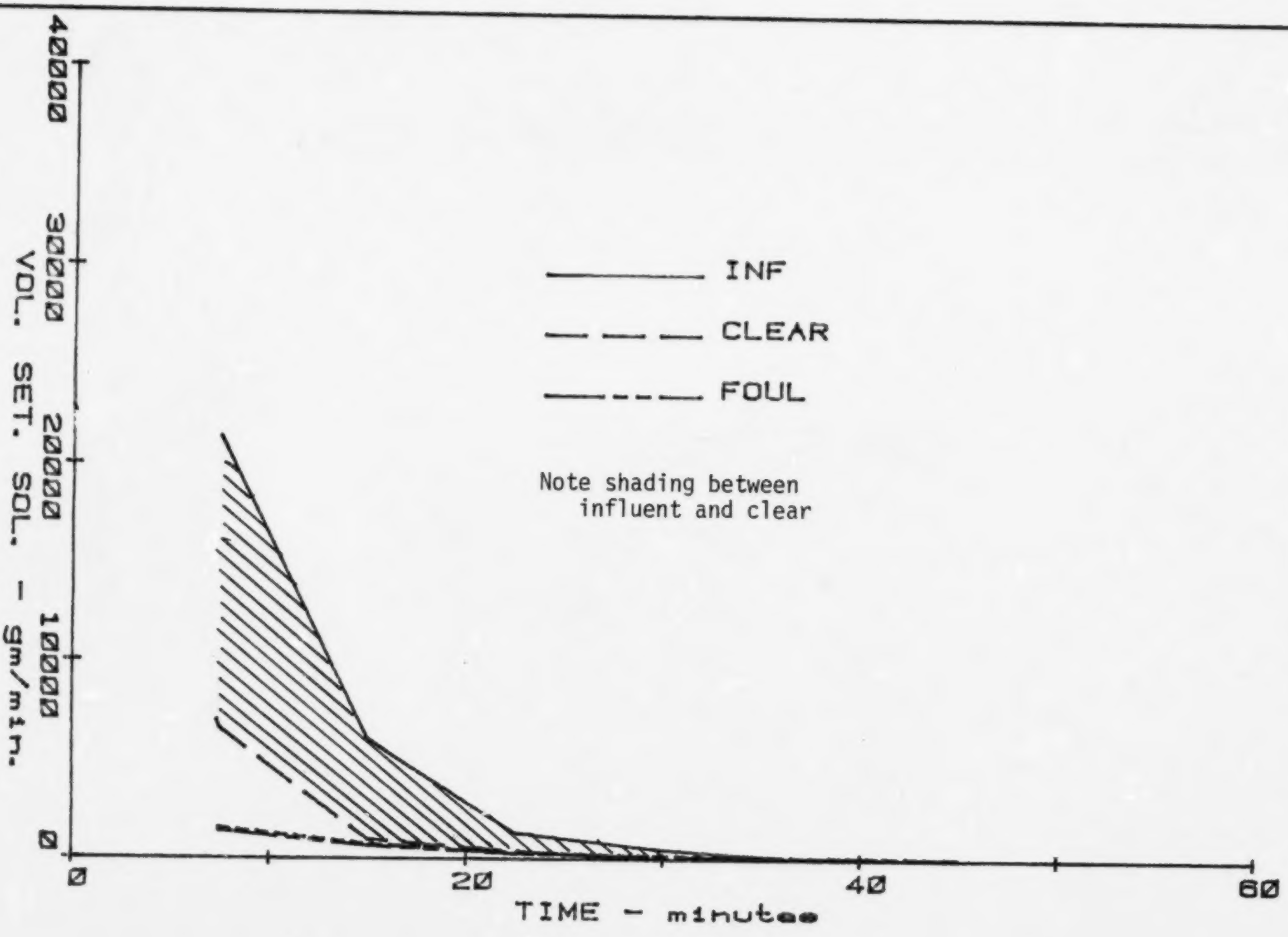


Figure 87. Volatile settleable solids mass vs time, Lancaster Swirl Concentrator/Regulator (9/10/80).

## Summary of Results 10/2/80

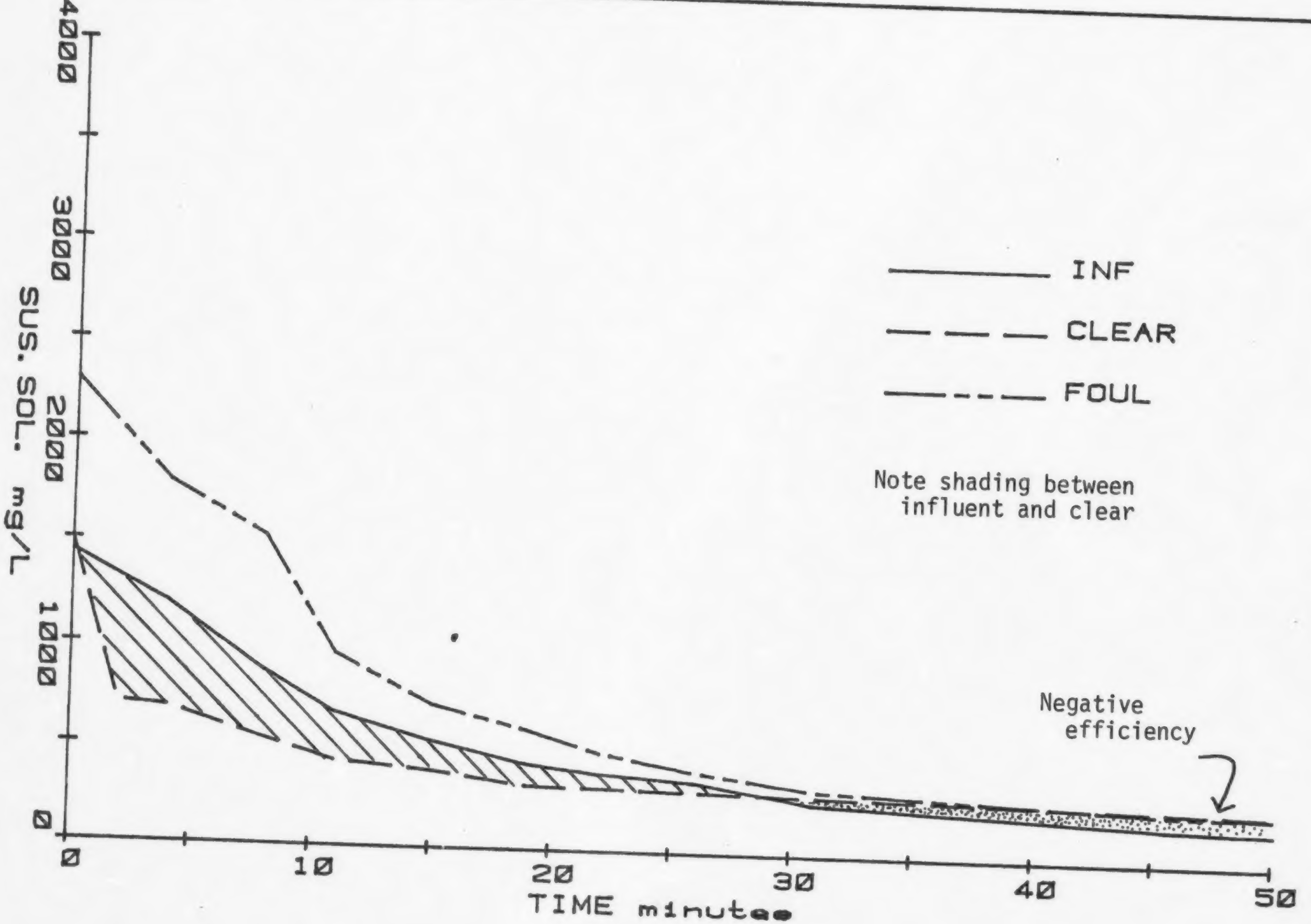
Swirl Concentrator influent, clear and foul suspended and settleable solids concentration vs time plots are presented in Figures 88 and 89 for the 10/2/80 event. Periods of positive and negative efficiency relative to the Swirl influent and clear solids levels are highlighted. Overall the sampling results from this event follow the trend noted throughout the program in that the highest efficiencies are at the storm's beginning. Poor efficiencies noted at later times may be attributable either to solids buildup within the swirl unit and/or to less concentrated, more dilute influent flow during these periods.

Based on estimated values, the flow pattern of this event started at an initial rate of 45 cfs (1274 l/s), decreased within 4 minutes to 17 cfs (481 l/s) and within 11 minutes to 7 cfs (198 l/s). After 20 minutes the flow was 2 cfs (56.6 l/s) for the remainder of the event. The influent solids concentration declined steadily from 1400 to 200 mg/l.

Clear overflow samples concentrations indicate efficiency rates of 20 to 50% with efficiency rate decreasing with flow and concentration. After 30 minutes the influent concentration continued to decrease. With flow at an approximate rate of 2 cfs (56.6 l/s) clear overflow was minimal. Clear solids concentrations were representative of tank liquid conditions so that comparison with influent values indicates negative removals. Although this may be due to the possible non-representative influent samples, low influent flow conditions is the probable reason.

During the latter portion of this event clear and foul sample concentrations were similar. With the flow too low to drive the swirling action required for treatment, the Swirl tended to act as a small detention tank. Since the clear solids concentrations did not drop in comparison to foul concentrations during this period, it might be inferred that the Swirl was of insufficient size to act as a detention tank even under low flow conditions. It should be noted that application of the suspended solids multipliers derived in section 12.4 would indicate greater overall efficiency.

Removals based on foul samples are estimated to be 12.3% at 17 cfs (481 l/s) using a foul flow concentration (ffc) factor see Section 11.6 of 1.4. At 4 cfs (113.3 l/s) the ffc of 1.65 indicates 58% removal. At 2 cfs (56.6 l/s) the average ffc of 1.27 indicates 95% removal.



Note shading between influent and clear

Negative efficiency

Figure 88. Suspended solids conc. vs time, Lancaster Swirl Concentrator/Regulator (10/2/80).

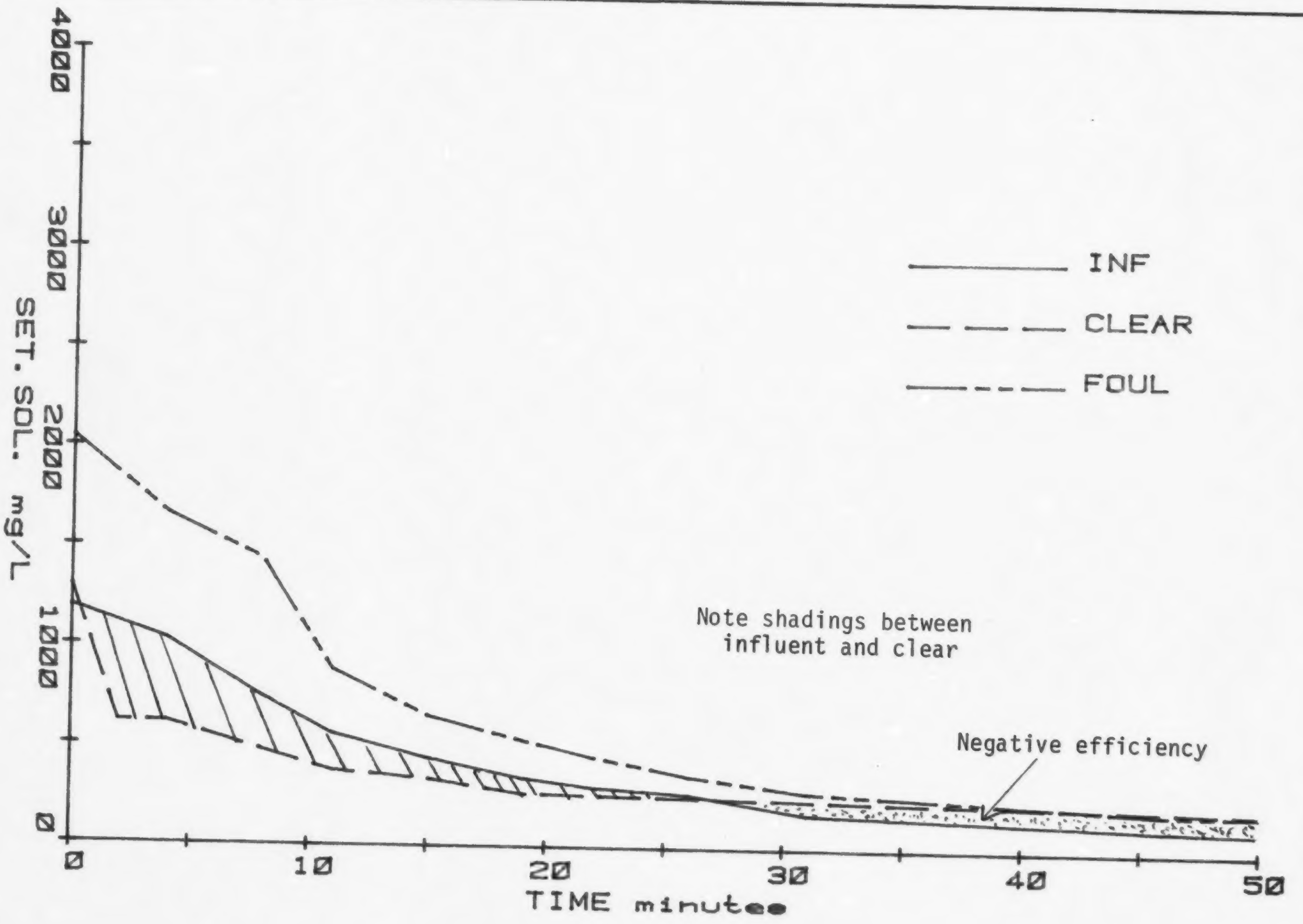


Figure 89. Settleable solids concentration vs time, Lancaster Swirl Concentrator/Regulator (10/2/80).

Results of samples tested for COD (see Figure 90) indicate similar efficiency rates as suspended solids samples. Based on influent suspended solids (SS) concentrations the influent COD can be related to the influent SS by the equation:

$$COD = -.5 + .61\ SS$$

with a correlation coefficient of 0.93 (N=11). These COD estimates can be adjusted using the multiplier factors derived in section 12.4. from the comparison of EDP Technologies Cross Sectional and Manning Samplers. Application of these factors would increase the initial influent COD concentration to a level greater than the initial clear value. Data as collected indicate COD removal rates between 25 to 54% with efficiencies up to 46%. The unadjusted results indicate reasonable Swirl efficiency and adjusting influent values would indicate even greater effectiveness.

## Summary of Results 7/2/81

During this event the foul sampler failed to operate and analysis is based on clear samples only. Flow rate estimates are questionable and no mass rates were determined. In general the flow began at about 20 cfs (566.4 l/s), rose to about 90 cfs (2549 l/s) at 6 minutes, fell to about 20 cfs (566.4 l/s) by 20 minutes and then remained near this level until the end of clear sample collection.

Influent and clear concentration vs time plots for suspended solids, volatile suspended solids, settleable solids and volatile settleable solids are shown in Figures 91-94, respectively. Inspection of these plots indicate that most of the influent suspended solids was settleable inorganic material. Influent suspended solids concentrations were high during the first five minutes and efficiency rates exceeded 80%. During the time the flow was decreasing, the influent solids concentration decreased sharply and efficiency averaged 70%. As the flow stabilized the influent concentration increased slightly and efficiency rate increased to an average of 80%.

## Summary of Results 5/10/81

Lack of clear sample collection during this event precluded the standard analysis. Suspended solids and settleable concentrations vs time plots for the Swirl Concentrator/Regulator are given in Figures 95 and 96 for this event. Foul samples collected in pairs by the EDP Technologies sampler demonstrated a concentrating effect of the influent solids.

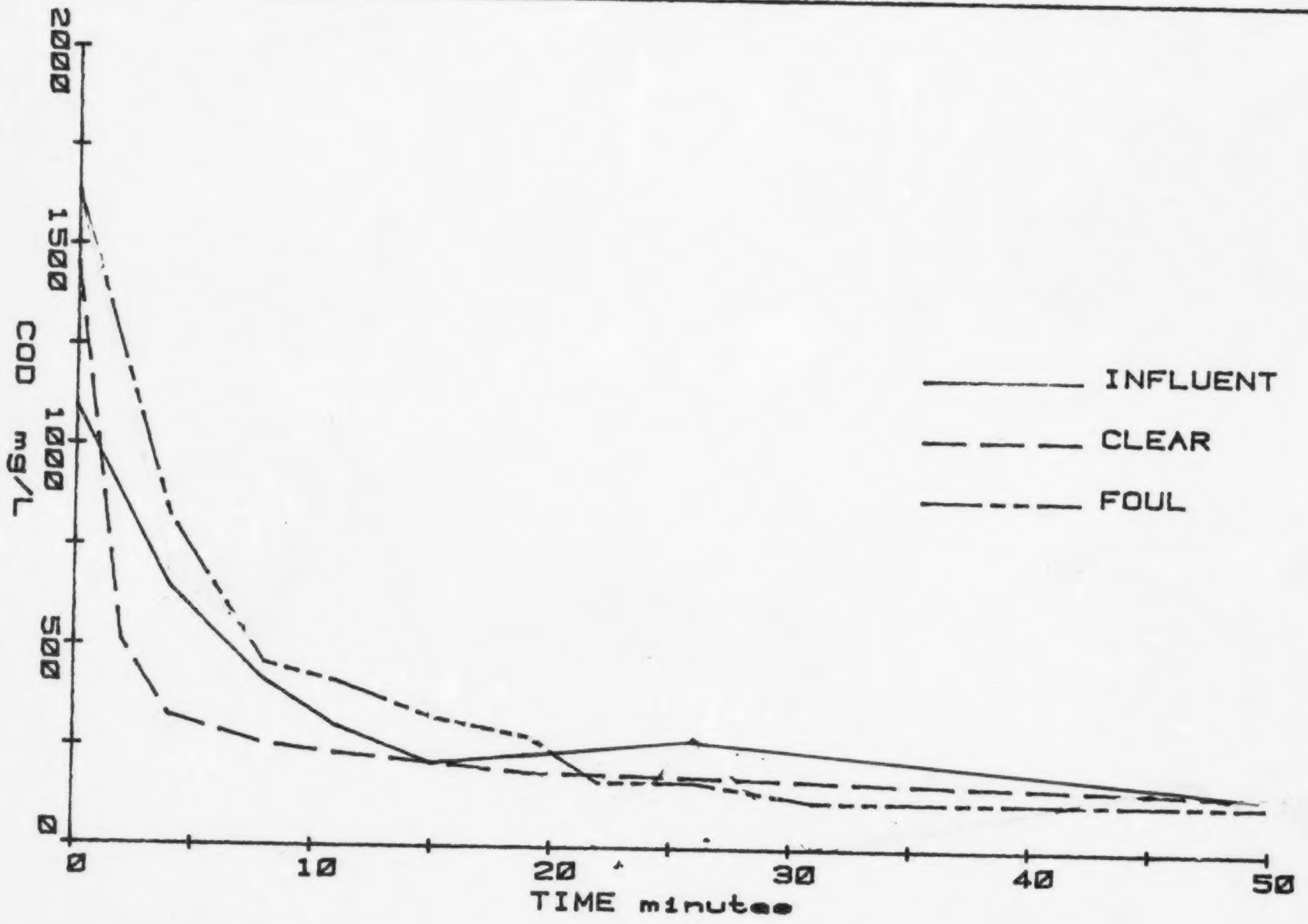


Figure 90. COD concentration vs time, Lancaster Swirl Concentrator/Regulator (10/2/80).

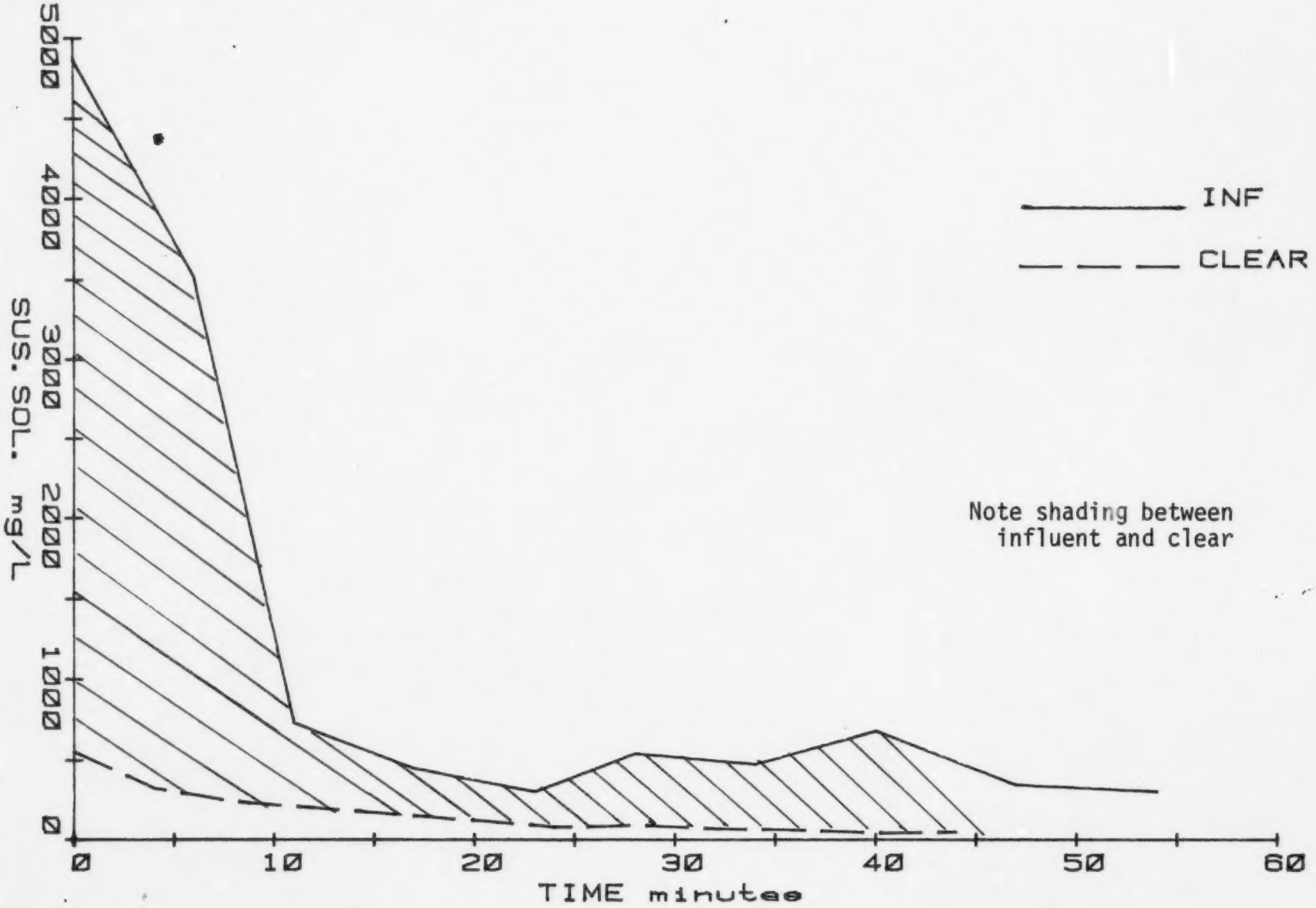


Figure 91. Suspended solids concentration vs time, Lancaster Swirl Concentrator/Regulator (7/2/81).

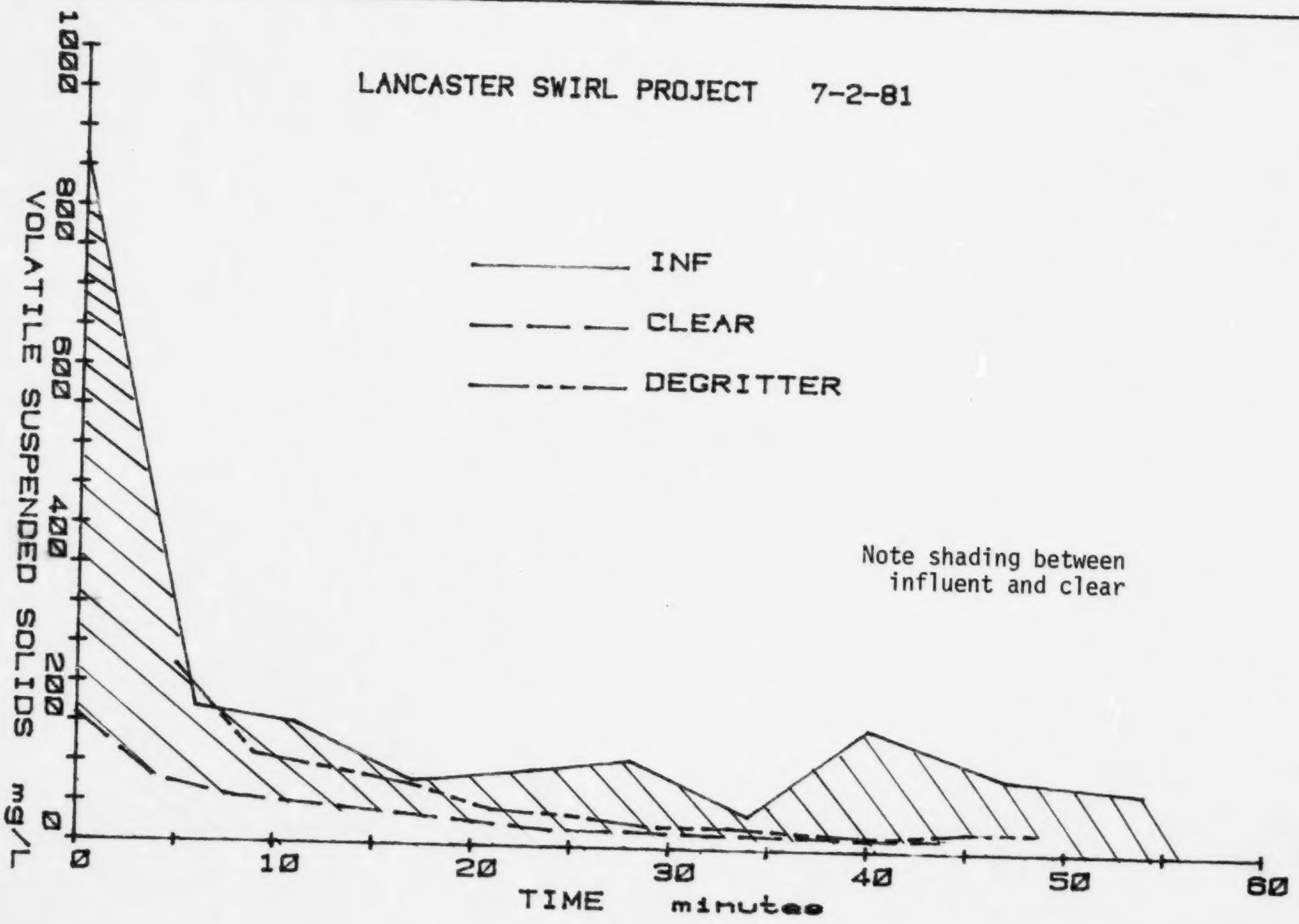
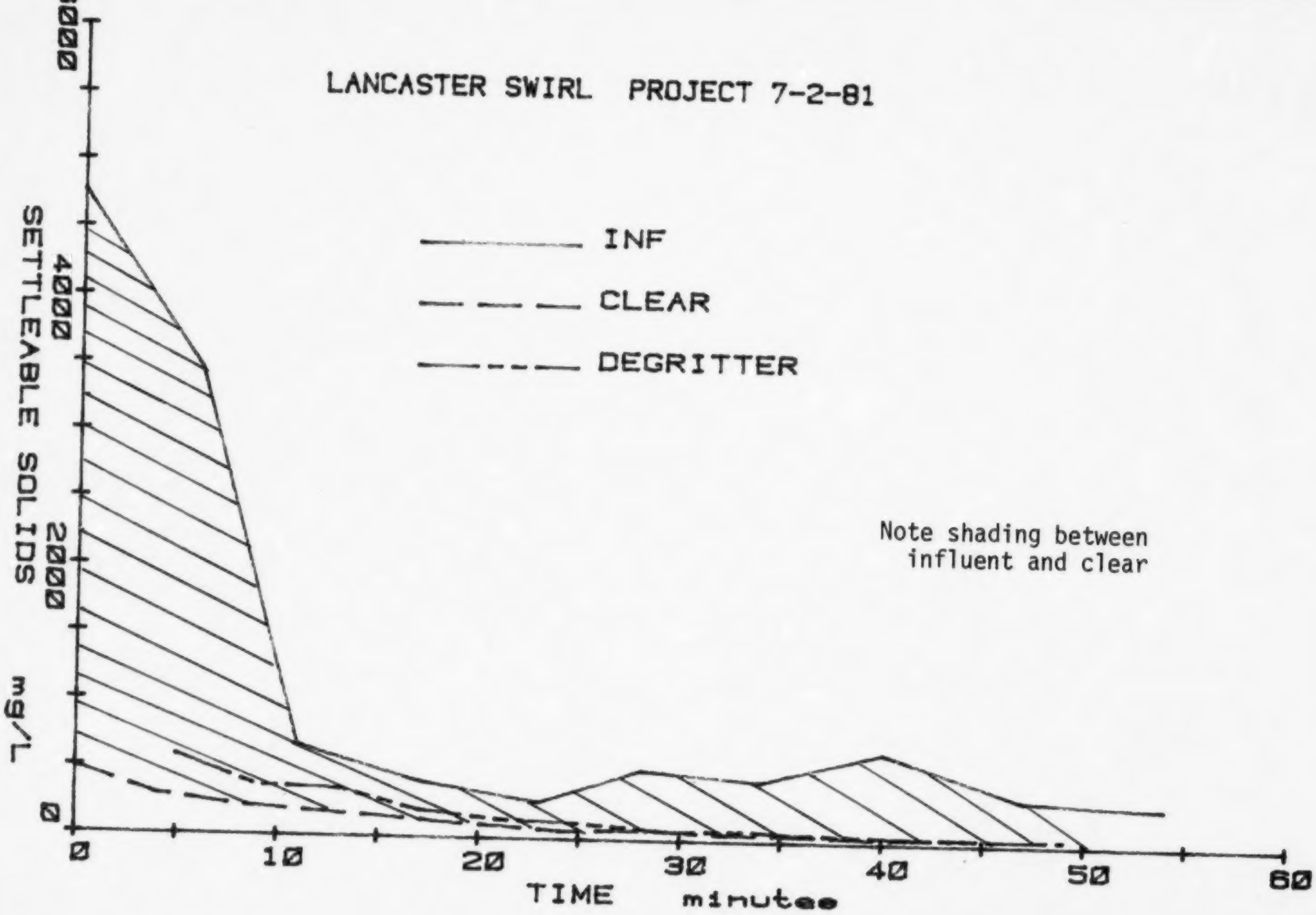
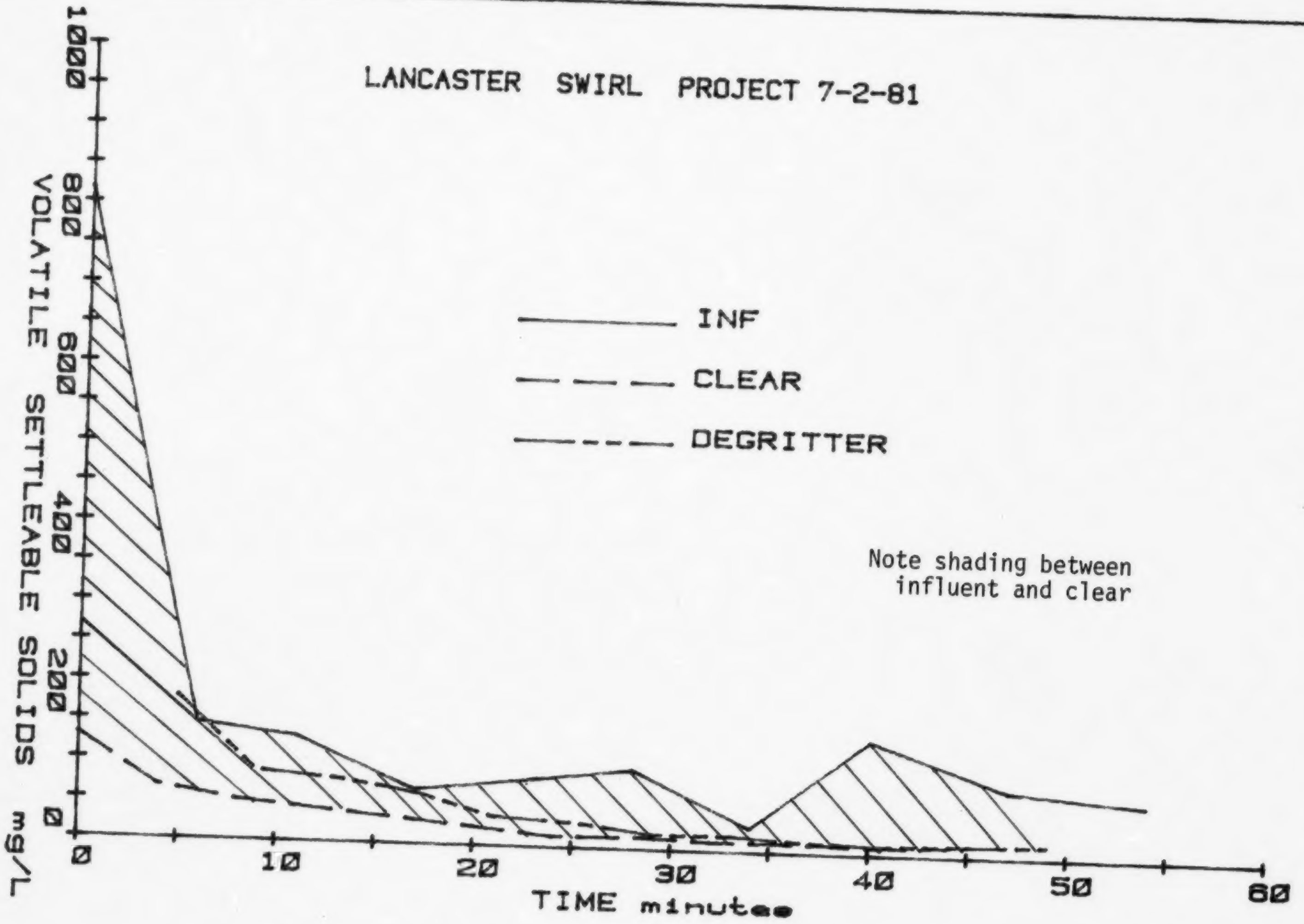


Figure 92. Volatile suspended solids concentration vs time Lancaster Swirl Concentrator/Regulator (7/2/81).



Note shading between influent and clear

Figure 93. Settleable solids concentration vs time Lancaster Swirl Concentrator/Regulator (7/2/81).



Note shading between
influent and clear

Figure 94. Volatile settleable solids concentration vs time
Lancaster Swirl Concentrator/Regulator (7/2/81).

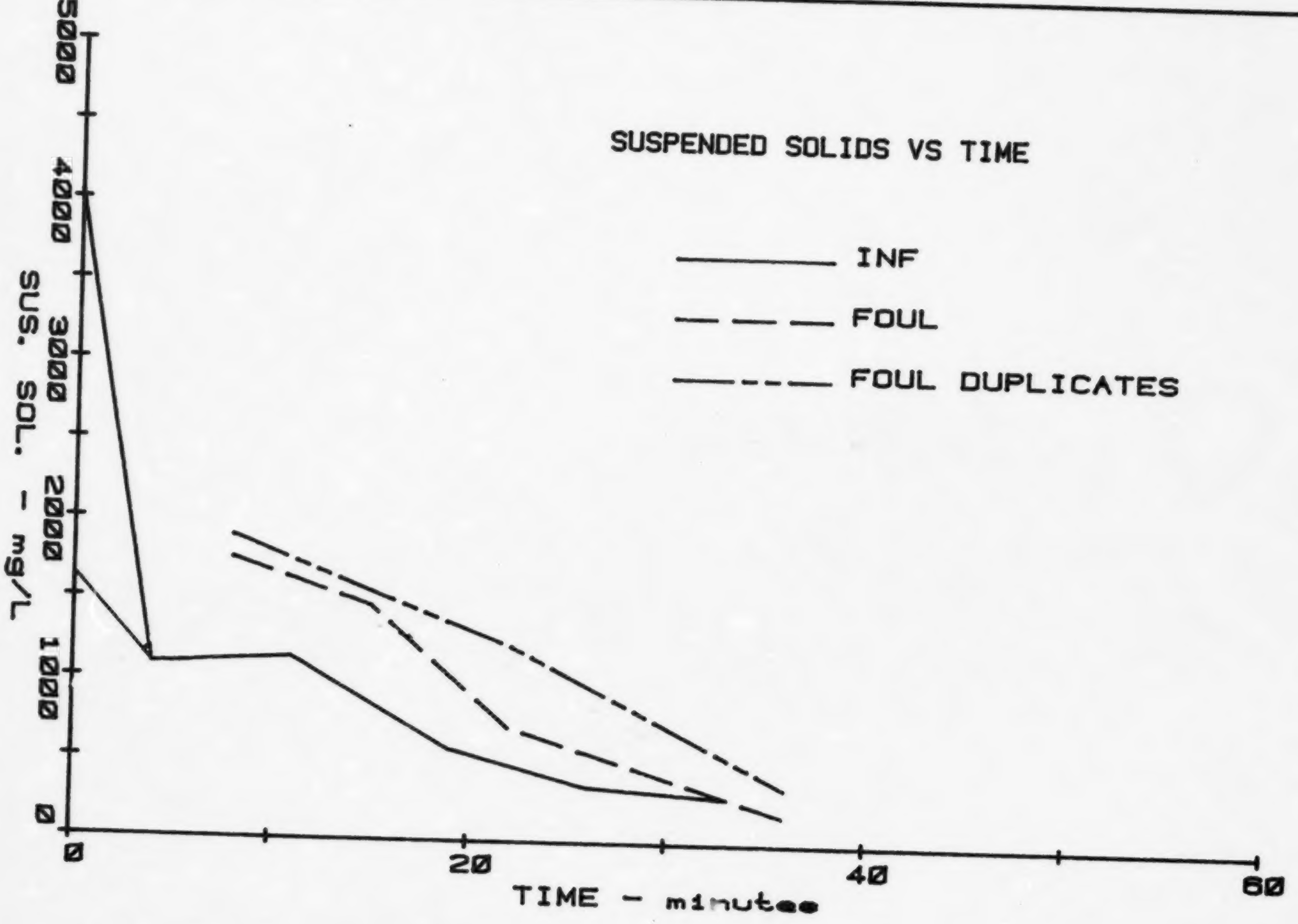


Figure 95. Suspended solids concentration vs time Lancaster Swirl Concentrator/Regulator (5/10/81).

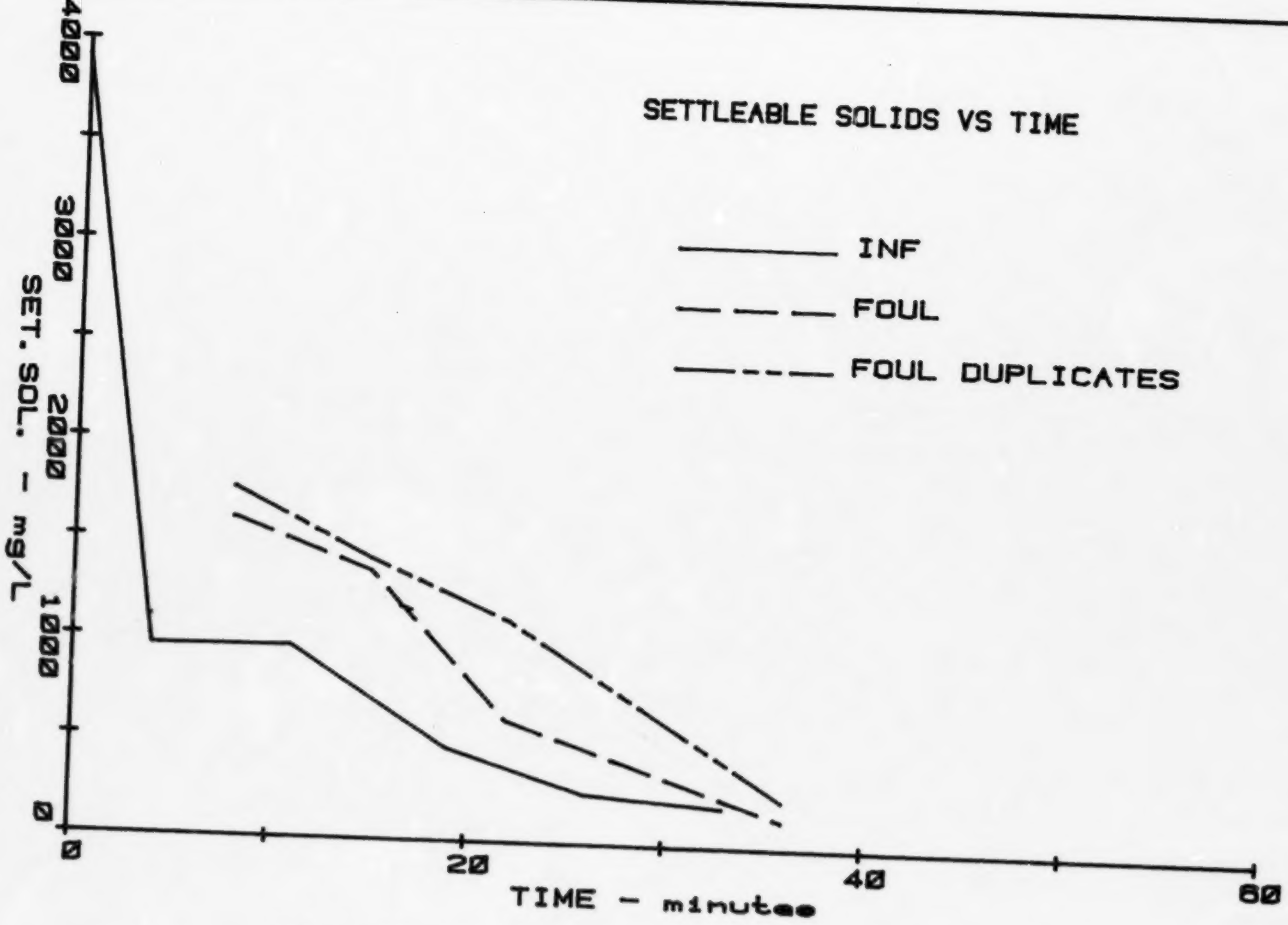


Figure 96. Settleable solids concentration vs time Lancaster Swirl Concentrator/Regulator (5/10/81).

Foul sample pairs consisted of samples taken one immediately after another with pairs separated by the standard sampling interval.

Comparison of the first two foul pairs indicates a 6% concentration discrepancy. This slight discrepancy is reasonable. At the 20 minute point in the event it was noted that some leakage occurred through the sampling unit between sampling intervals.

For the purpose of evaluating this event the second sample of each pair (lower curve in Figures 95 and 96 labelled "foul duplicate") was used during evaluations to eliminate any bias due to leakage. Foul sample suspended solids concentrations averaged 1.65 times the influent concentration during ten minutes of foul sampling. During the next ten minutes the foul concentrating effect decreased to 1.30.

Approximate influent flow rates were 20 cfs (566.4 l/s) at 10 minutes, 8 cfs (226.3 l/s) at 20 minutes and 6 cfs (170 l/s) at 30 minutes. At the ten minute mark with an approximate influent flow rate of 20 cfs (566.4 l/s), a foul flow rate of 1.5 cfs (42.5 l/s) and a concentrating factor of 1.65, the removal rate is estimated as 12.3%. Similarly removal rates at 20 and 30 minutes are 22.5 and 35%.

In addition to the standard discrete sample analysis the Swirl tank was hand-sampled at the end of the event. Six samples were collected from within the Swirl tank at the end of unit operation. Three of the samples were representative of solids concentrations in the top 3 ft (91.4 cm) of the tank at various positions around the tank. Three additional samples were representative of the solids concentrations from the surface to the tank bottom. Visual observation of the clear plexiglass sampling tube indicated that a 10 in. (25.4 cm) sludge blanket existed at the tank bottom. These samples were collected at positions midway between the tank outer wall and the scum baffle. Although this sludge blanket somewhat verified the notion of solids buildup during unit operation the samples were taken 20 minutes after clear overflow ceased and sampling ended. No mass balance was possible due to lack of interim samples, and the degree of settling of tank solids could not be determined.

## Summary of Results 7/20/81

Figures 97-100 present concentrations vs time plots of suspended solids, volatile suspended solids, settleable solids and volatile settleable solids for the Swirl Concentrator/Regulator. Inspection of these plots indicate that

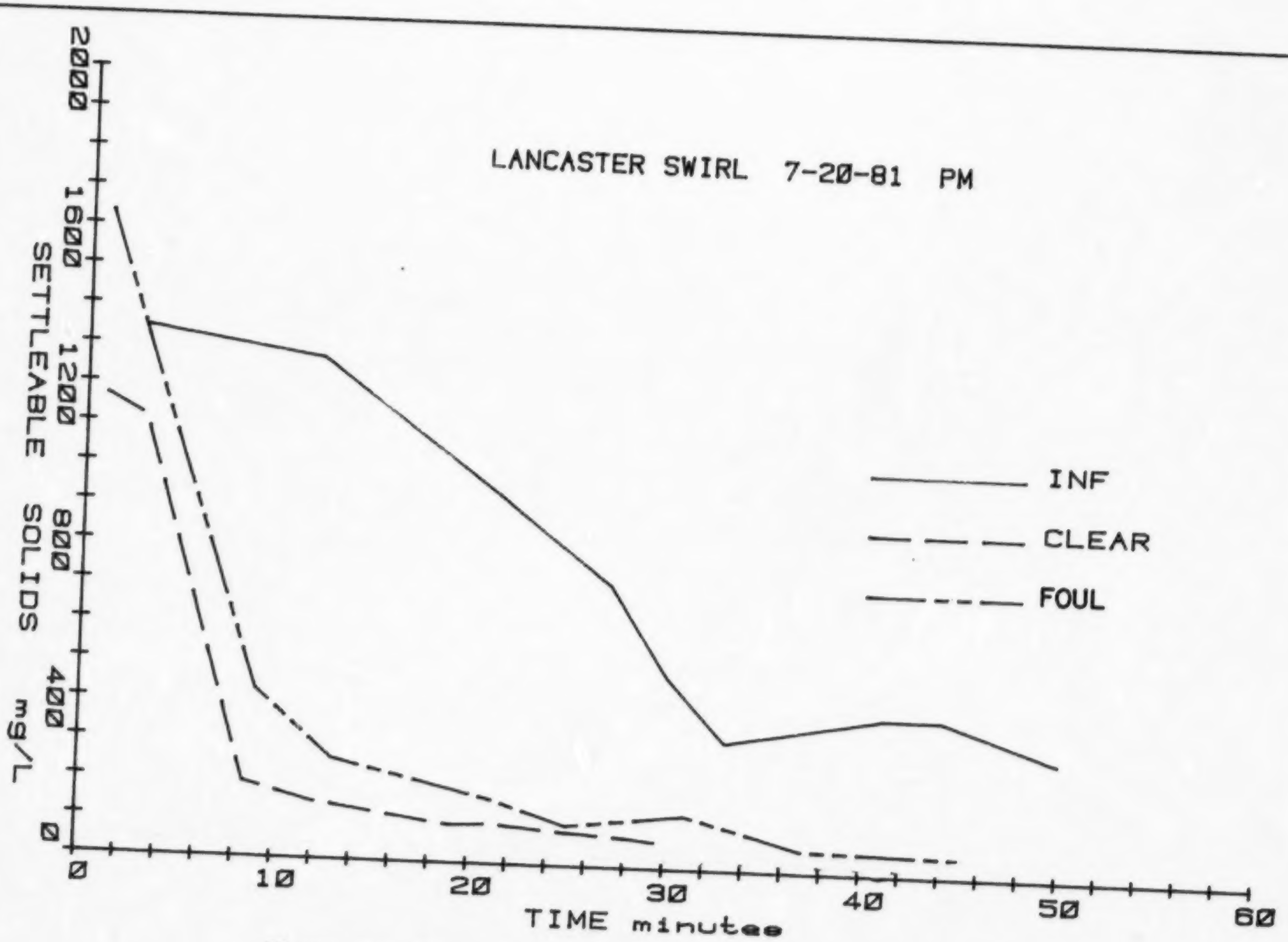


Figure 97. Suspended solids concentrations vs time Lancaster Swirl Concentrator/Regulator (7/20/81).

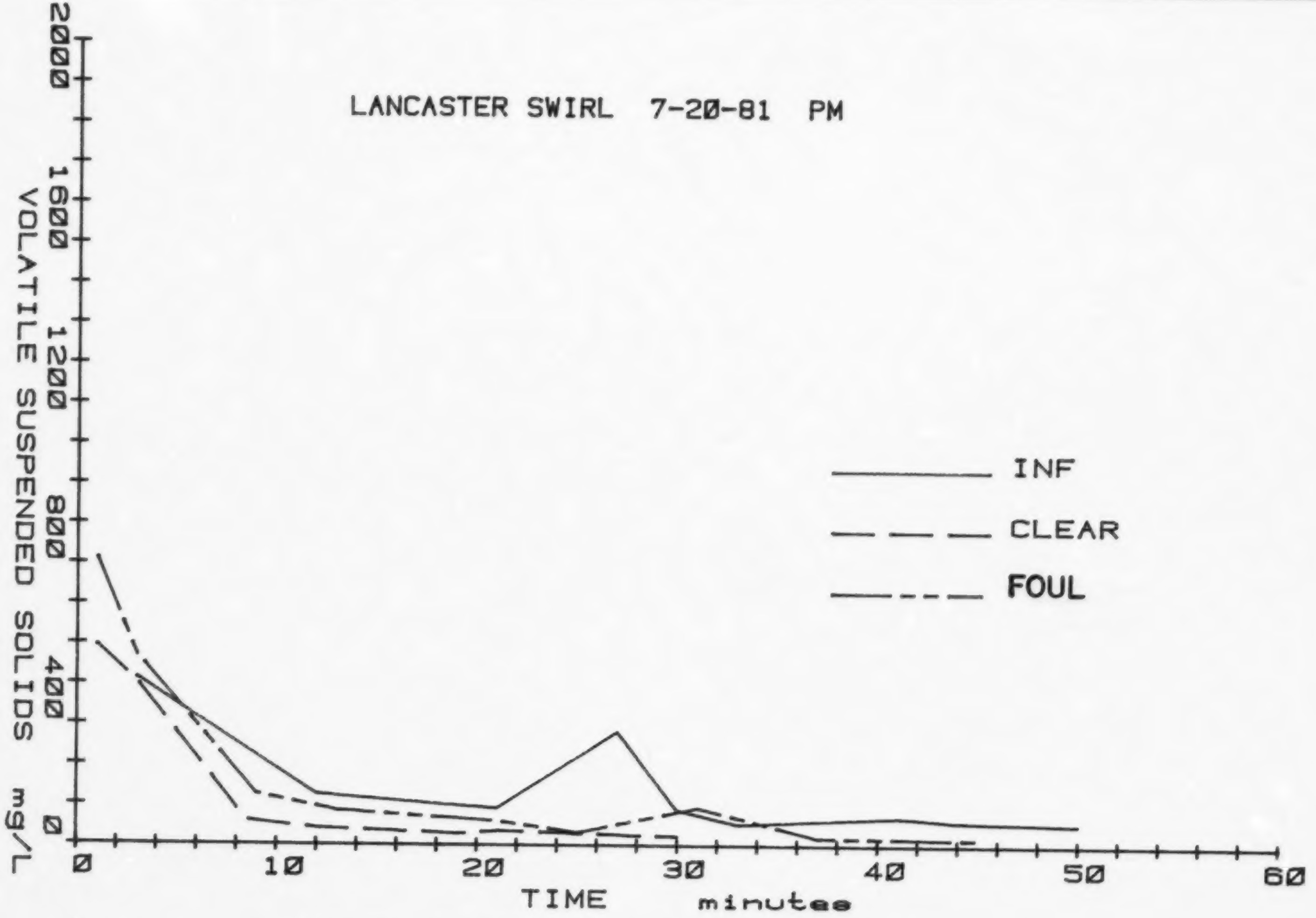


Figure 98. Volatile suspended solids concentrations vs time Lancaster Swirl Concentrator/Regulator (7/20/81).

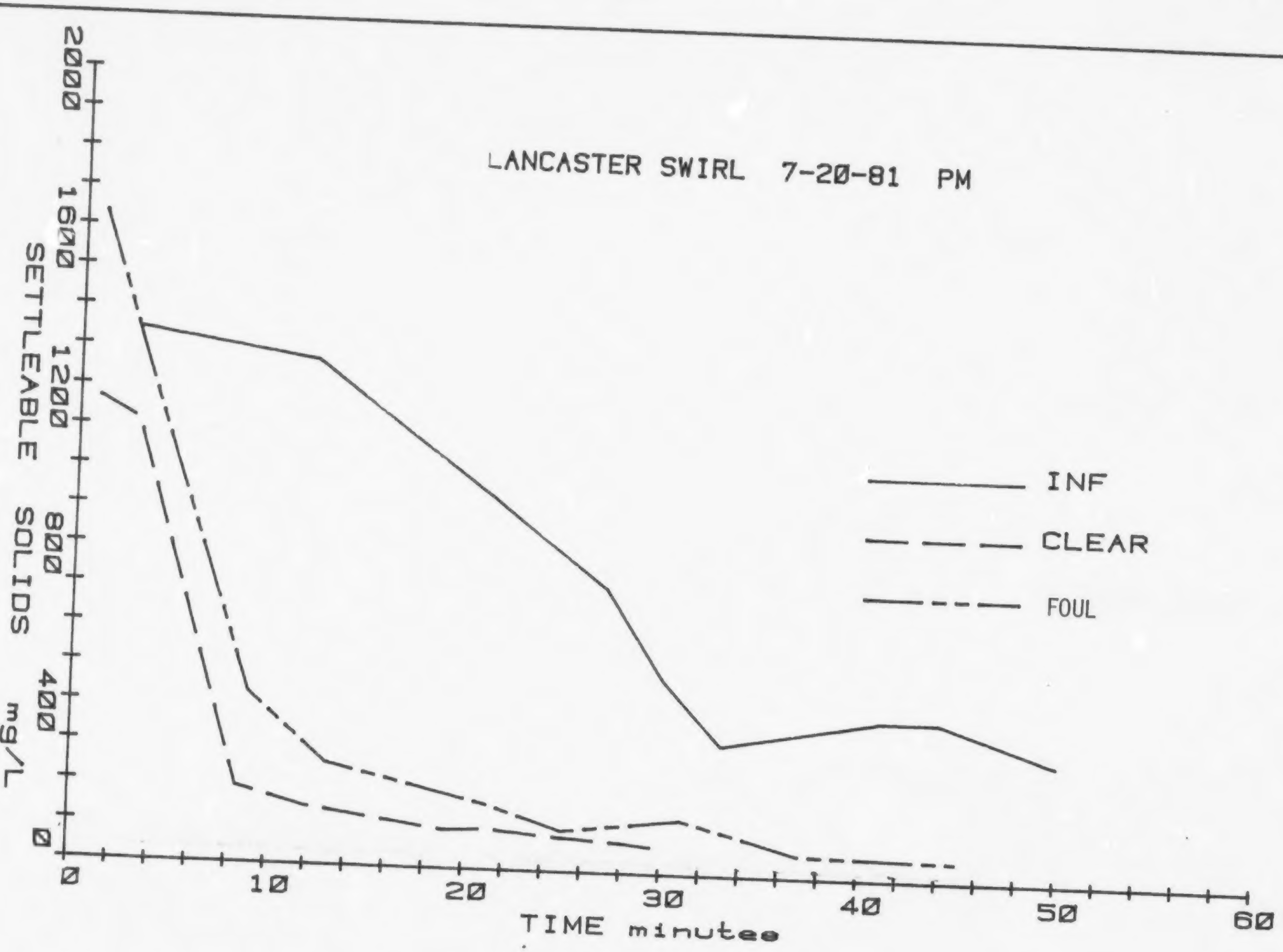


Figure 99. Settleable solids conc. vs time, Lancaster Swirl Concentrator/Regulator (7/20/81).

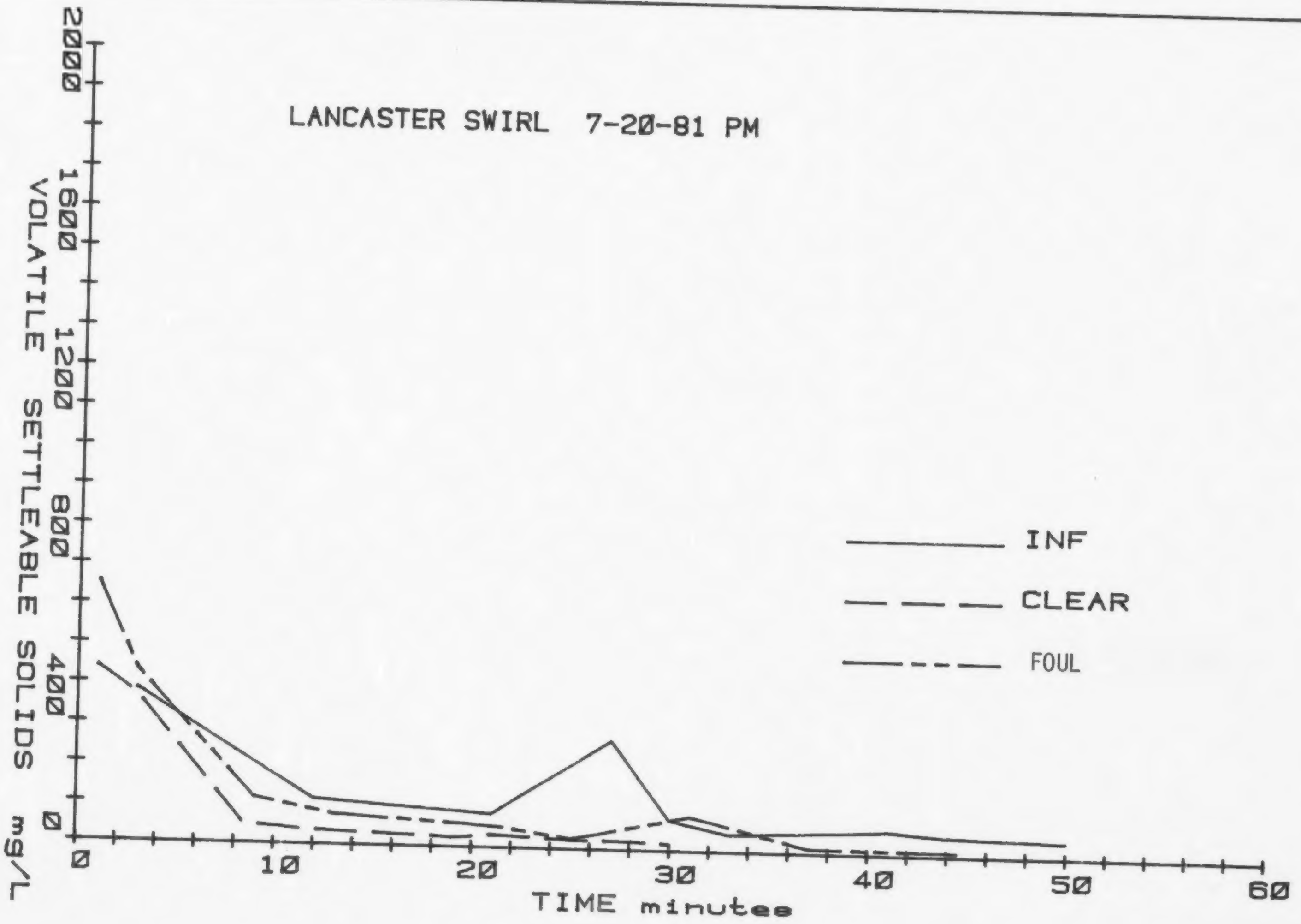


Figure 100. Volatile settleable solids conc. vs time, Lancaster Swirl Concentrator/Regulator (7/20/81).

most of the suspended solids is inorganic settleable material. Clear samples concentration were consistently much less than influent values during this event. Influent flow estimates include a low flow at first with 4.5 cfs (127 l/s) at 3 minutes, rising to 37 cfs (1048 l/s) at 11 minutes and up to a peak of 56 cfs (1586 l/s) at 27 minutes. Estimated flows remained high for the duration of sampling decreasing to only 30 cfs (850 l/s) at the 50 minute mark.

At the beginning of the event the removal rate was 41% with an efficiency of 11% based on the low level flow. Clear solids concentration dropped quickly while the influent increased resulting in an average removal and efficiency rates of 83% and 80% during the 20 minute clear sampling period at flows above 35 cfs. (991 l/s).

## Section 12.6. REASSESSMENT OF EARLY PROGRAM DATA

The results of the storm events just presented indicate that during those events the Swirl operated as an effective solids separation device. During many of the earlier events in 1978, 1979 and even for several storms in the fall of 1980, the results were not as conclusive. In fact, the opposite conclusion was true - the Swirl Concentrator did not seem to provide any treatment.

not

The analysis presented in this section is intended to provide inferential evidence that the Swirl Concentrator/Regulator was in fact providing reasonable solids treatment removal during those periods. The influent suspended solids multipliers derived from sampling equipment differences are used to reassess influent concentration levels to the Swirl.

Two of the four 1980 events monitored by EDP were previously discussed in Section 12.5 and had demonstrated good efficiencies. The 8/10/80 event was noted to include samples of questionable quality and was dropped from consideration. The fourth event occurred on 9/14/80. Although low treatment efficiency was noted, review of the raw performance data in light of the potential sampling bias indicates higher removal rates. Numerous events were monitored during 1978 and 1979 and few indicated positive efficiency results. The 6/21/78 storm was deemed representative of these events and reviewed again. Revised results indicated solids treatment.

Section 12.4 discussed in detail the relative efficiencies of the Manning sampler and the new EDP Technologies Cross-Sectional sampling unit during collection of influent samples. It was shown that EDP unit samples were several times more concentrated and the relative concentrations were related to the time of sampling. Data from the 9/14/80 event and the 6/21/78 event were reviewed considering these concepts. Table 15 includes the original influent data and influent data adjusted by appropriate concentration factors. Original and adjusted removal rates and efficiencies were determined for the 9/14/80 event. Originally the efficiency rate was zero for the first sample and/ranged up to 30%. Suspended solids efficiency rates exceeded 38%. Overall, the adjusted data indicates effective swirl operation throughout the event.

Similarly, the original 6/21/78 event data shown in Table 15 indicated poor performance. Most sample sets included clear sample concentrations much higher than found in the influent. Adjusting the actual influent concentrations by the factors developed earlier yields values higher than clear sample values. Removal rates which were low or negative based on original values were calculated to be 20% to 56% on an adjusted solids concentrations basis.

Table 15
9/14/81 Analytical Data

| TIME (MIN.) | FLOW cfs | INFLUENT (mg/l) | CLEAR OVERFLOW (mg/l) | % REM | %EFF |
|---|---|---|---|---|---|
| 0 | 22 | 550 (3300)* | 1280 | - (74) | - (57) |
| 7.5 | 43 | 500 (3000) | 350 | 32 (88) | 29 (85) |
| 15 | 24 | 350 (1440) | 250 | 33 (83) | 27 (77) |
| 22.5 | 11.6 | 220 (440) | 200 | 24 (60) | 11 (47) |
| 30.0 | 6.5 | 110 (220) | 110 | 23 (61) | 0 (38) |

* adjusted values in parenthesis ( )

6/21/78 Analytical Data

| Time Min. | Influent mg/l | Clear Overflow mg/l | % Rem** |
|---|---|---|---|
| 7.5 | 47 ( 329) | 822 | - - |
| 15.0 | 261 (1255) | 913 | - (27) |
| 22.5 | 179 ( 537) | 386 | - (28) |
| 30.0 | 104 ( 312) | 249 | - (20) |
| 37.5 | 92 ( 276) | 163 | - (41) |
| 45.0 | 74 ( 222) | 124 | - (44) |
| 52.5 | 77 ( 154) | 68 | 12 (56) |
| 60.0 | 56 ( 112) | 70 | - (38) |

** no flow data available and efficiencies not calculated

## 12.7. Ancillary Sampling Considerations Swirl Concentrator Tank Samples

Tank samples were collected from within the Swirl chamber at the end of unit operation during four events : 5/10/81, 6/22/81, 7/2/81 and 7/20/81. Three samples were taken within the upper third of the tank at various positions around the tank while three additional samples were taken in the lower third. Samples were collected at positions midway between the tank outer wall and the scum baffle.

Suspended solids concentrations of tank samples from the 6/22/81, 7/2/81 and 7/20/81 storm events approximated solids levels from clear samples indicating that there was little solids accumulation within the unit during its operation. Samples from the 5/10/81 event had a higher suspended solids concentration in the lower depth sample stations. This concentration effect may have been due to a delay of 20 minutes in starting hand sampling. During this 20 minute period after unit shutdown, solids began to settle in the tank causing the formation of a sludge blanket on the unit floor.

### First Flush Mass

Most of the events monitored at Lancaster exhibited initial high concentrations occuring at the start of the event followed by decreased levels with time of operation. Visual observations of pre-storm conditions indicated that the diversion chamber and 5 ft (1.5 m) pipe leading to it acted as a settling basin during dry weather flow. This was largely due to debris caught on the bar rack creating backwater in this area. The question arises as to how much of the "first-flush" materials seen in sampling event are actually due to this accumulation as opposed to the runoff materials typical of the area.

For two of the storm events exhibiting high "first-flush" effects the mass of solids entering the Swirl during the unit was calculated. From this value and the diversion chamber dimensions the depth of solids accumulated within the chamber prior to the event required to produce such a mass flow was calculated. A solids density of 75 lb/ft.$^3$ (1.2 g/cc) (sg = 1.2) and a moisture content of 90% were assumed for materials accumulated in the diversion chamber.

Calculations indicate that the solids-liquid mixture had to have been 13 to 19 ft (396 cm to 579 cm) in depth in the diversion chamber area ahead of the bar rack or 5 to 7 ft

(152 to 213 cm) deep in the entire chamber to have accounted for the entire "first-flush" mass. These numbers could be reduced somewhat considering accumulations in the 5 ft (152 cm) influent pipe to the chamber but in any case it is clear that most of the material noted during "first-flush" was not diversion chamber accumulations.

## 12.8 Settleability Experiments- Swirl Concentrator Regulator

Before the EDP evaluation program had commenced, a flow-through hand sampling device with trigger-activated slide-down gates was forwarded along with sample vessels and sampling instructions to Lancaster to collect a set of influent samples. A settleability experiment was completed in January 1980. Eight additional experiments were conducted during the evaluation program covering the settleability characteristics of the influent and clear overflow. All mixing and settling was performed using the state-of-the-art settleability column detailed in Chapter 11.

Analysis of Swirl Concentrator/Regulator settleability sample results is reported in two parts. In section 12.8.1 all settleability data are compared by simultaneous plotting to demonstrate the effects of initial solids concentration and sampling technique on settleability characteristics. In section 12.8.2 each event was reviewed where feasible to determine the overall removal and the degree of removal at various settling velocities.

### 12.8.1 Comparative Summary of Swirl Influent Settleability Characteristics with Discrete Sampler Results

A comparison of all obtained suspended solids settleability curves and Swirl influent suspended solids concentrations noted during first 20 minutes using discrete sampling is shown in Figure 101. The settleability plots were derived from settling column testing and evaluation of 30 gal (113.5 l) samples collected as early as possible during an event. Suspended solids concentration ranges are those noted by discrete automatic sampling during the first 20 minutes of each event. For each event the highest obtained discrete concentration occured within the first sample and the least concentration within the 20 minute sample. This is due to the first sample being taken after the Swirl tank began to fill and the "first-flush" in progress. Twenty minutes generally allowed sufficient time for the "first-flush" to pass and dilute stormwater to flow.

In Figure 101 the data as shown indicate the storm dates with matching symbols used to label each data set. Influent suspended solids concentrations ranges obtained by discrete

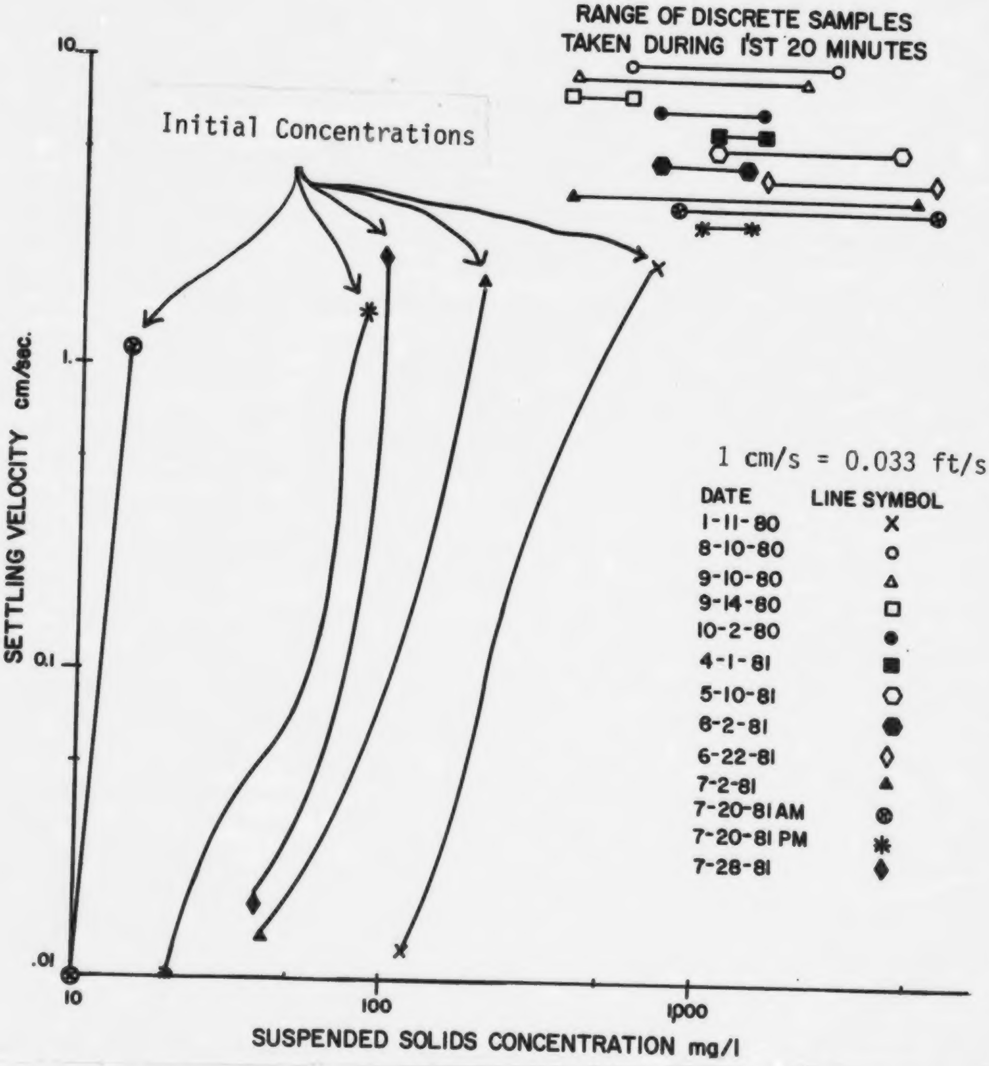


Figure 101. Lancaster Swirl Concentrator/Regulator, influent, Comparison of settling column analysis with discrete sampler results.

samplers are included for all sampled events. Settleability data are included for influent flow samples for five storm events. Significant aspects of settleability samples as demonstrated by simultaneous plotting are the range of initial concentrations and the varying percentages of solids fractions within settling velocity ranges.

The settling curve plots in Figure 101 illustrate that those curves with the highest initial concentrations have a greater percentage of solids with high settling velocities and contain solids fractions within all ranges. Comparison of the settleability data to discrete sampling data in Figure 101 indicates that in most instances the initial settleability sample concentrations were less than the range of solids encountered during the first twenty minutes of discrete sampling.

For those storm events where clear overflow settleability analysis (not shown in Figure 101) were performed, the range of initial concentrations was narrow (60 to 140 mg/l) while simultaneously collected influent samples ranged in initial concentration from 18 to 200 mg/l. Clear settleability samples were typically closer to clear discrete sample values than the corresponding set of influent settleability and discrete samples.

The significance of Figure 101 is that those influent settleability samples which were similar to discrete influent concentrations also resulted in the best overall removals (in comparison to clear overflow settling curves) and that removal rates increased as settleability samples approached discrete sample concentration levels. Thus, suspended solids treatment efficiency could only be demonstrated by settleability samples representative of "early-event" conditions. In reality some of the influent samples were not representative due either to sampling late in the event or to inadequate sampling techniques or both.

The initial range of influent and clear discrete sampler data and the settling column results for the 7/2/81 event are depicted in Figure 102 and illustrate the problem. The initial clear settleability sample concentration is similar to the discrete sample concentration within the first twenty minutes. Settleability samples were collected over a 25 minute period starting several minutes after initial discrete sampling. The influent settleability sample which was collected simultaneously with the clear sample, did not contain solids concentrations similar to discrete influent samples collected during this time. This discrepancy is probably due to the sampling techniques used. Clear samples

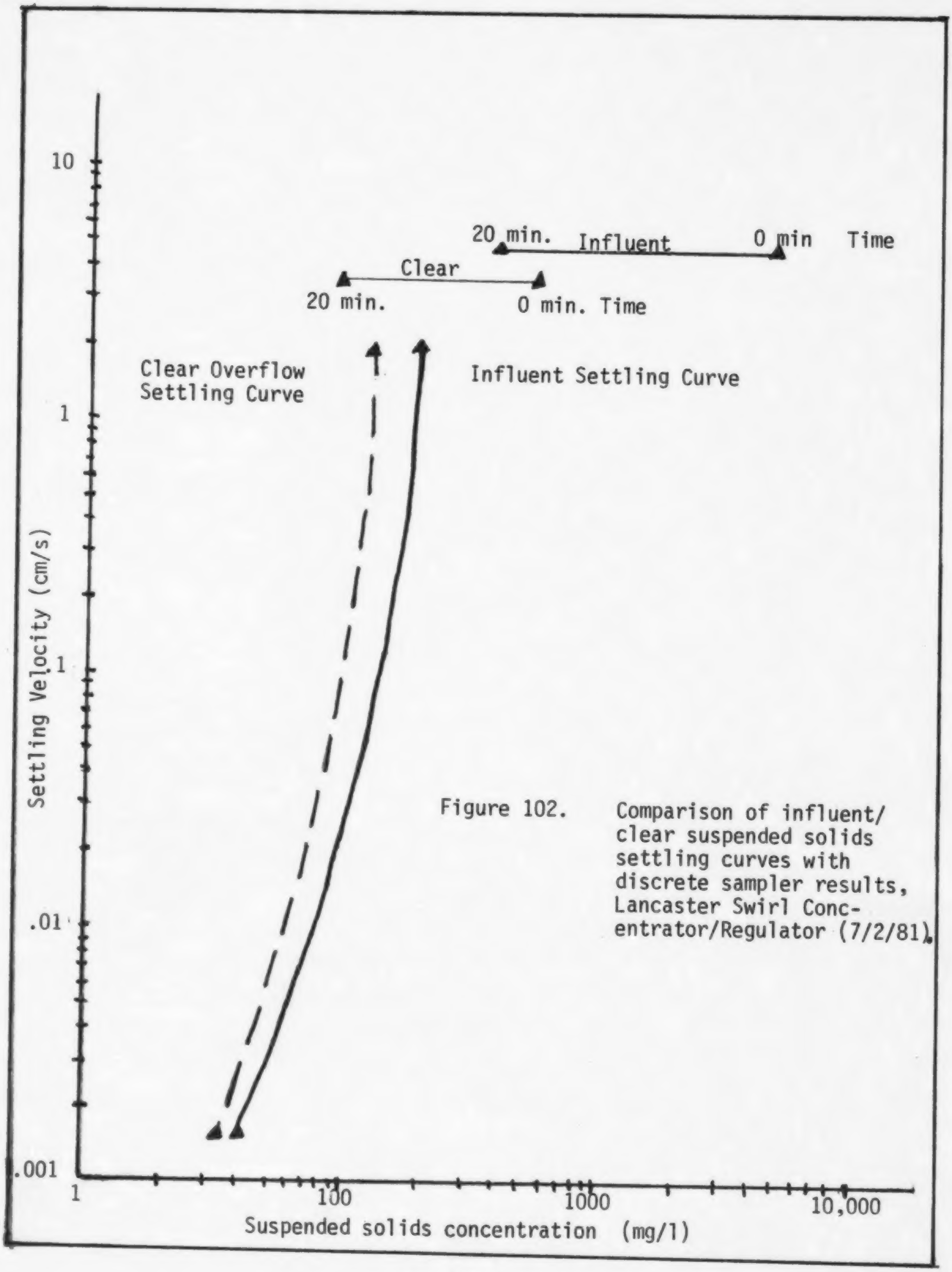


Figure 102. Comparison of influent/clear suspended solids settling curves with discrete sampler results, Lancaster Swirl Concentrator/Regulator (7/2/81).

were collected by allowing a complete slug of water to flow into a bucket within the central clear down pipe. The bucket was removed as soon as it filled. This technique eliminated the possibility of material bypassing the bucket.

Several influent sampling techniques were attempted and it appears that none could adequately deliver a large representative sample in comparison to discrete sampling results. This problem had been noted earlier and and led to the design, manufacture and installation of the EDP Technologies Cross Sectional sampler. This unit was designed for small volume samples (1l) and the number of sampling cycles required to obtain an adequate settleability sample, 30 gal (104 l) during the 5 to 10 minutes in which the "first-flush" usually passed, was mechanically prohibitive.

In sum, adequate and representative samples were obtained by the influent/ clear discrete sampling techniques and the clear settleability sampling technique. Influent settleability results are questionable. Analysis of Swirl solids treatment efficiency based on influent and clear settleability results are questionable and on the low side. Conclusions reached in this evaluation regarding Swirl treatment performance are based on discrete sampling results.

The proposed "grit and organic" curves shown on Figure 6, Chapter 4, indicate that most of the solids to be removed had settling velocities between 1 to 10 cm/sec (.032 - .33 ft/sec). The settling curve plots in Figure 101 indicate little materials in this range. Discrete sampler results on Figure 101 would seem to indicate more material actually present.

### 12.8.2. Comparison of Theoretical With Actual Performance Removal

In this section the performance comparing measured influent and clear solids settleability results are compared with theoretical removal results as computed using formalisms developed elsewhere (4).

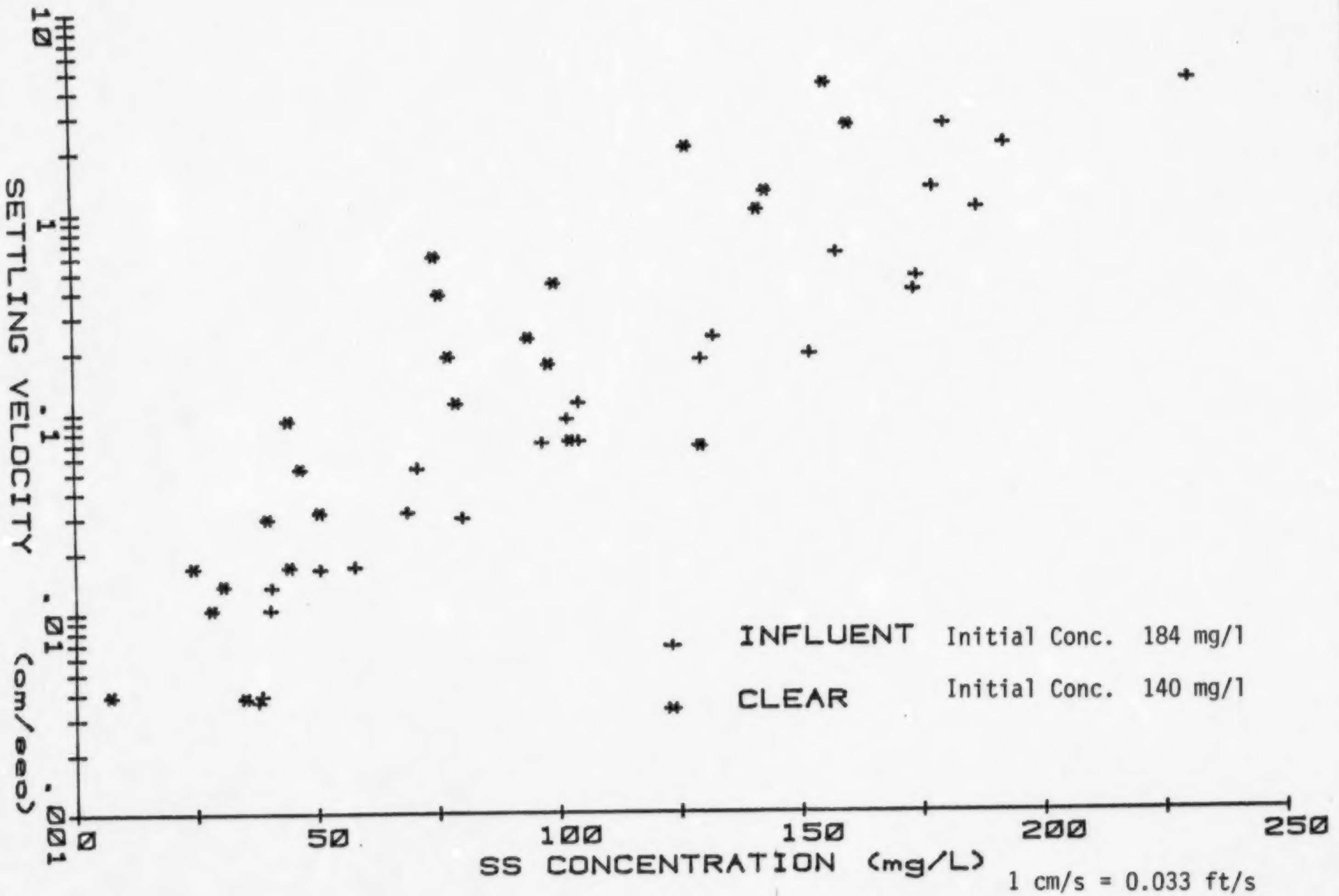
Liquid flow velocities (from either the mathematical model or physical model) for a Swirl Concentrator/Regulator of size, $S_1$ can be scaled to represent the flow in a geometrically similar concentrator of size $S_2$ using Froude number scaling.

Settleability samples were collected from the Swirl influent and clear overflow streams on 7/2/81, during the AM and PM events on 7/20/81 and on 7/28/81. Previously, the influent only had been sampled on 1/11/80.

Each of these data sets are graphically displayed in Figures 103-106 by plotting suspended solids concentration vs settling velocity. It is obvious that no treatment is evident based on the samples collected during the 7/20/80 am/pm and 7/28/81 events. The initial concentration is defined as the average concentration of three samples taken from the column immediately after complete mix. In these three sample sets the initial clear concentration was substantially higher than the influent value. This could be due to sampling methods or relative sampling times or both.

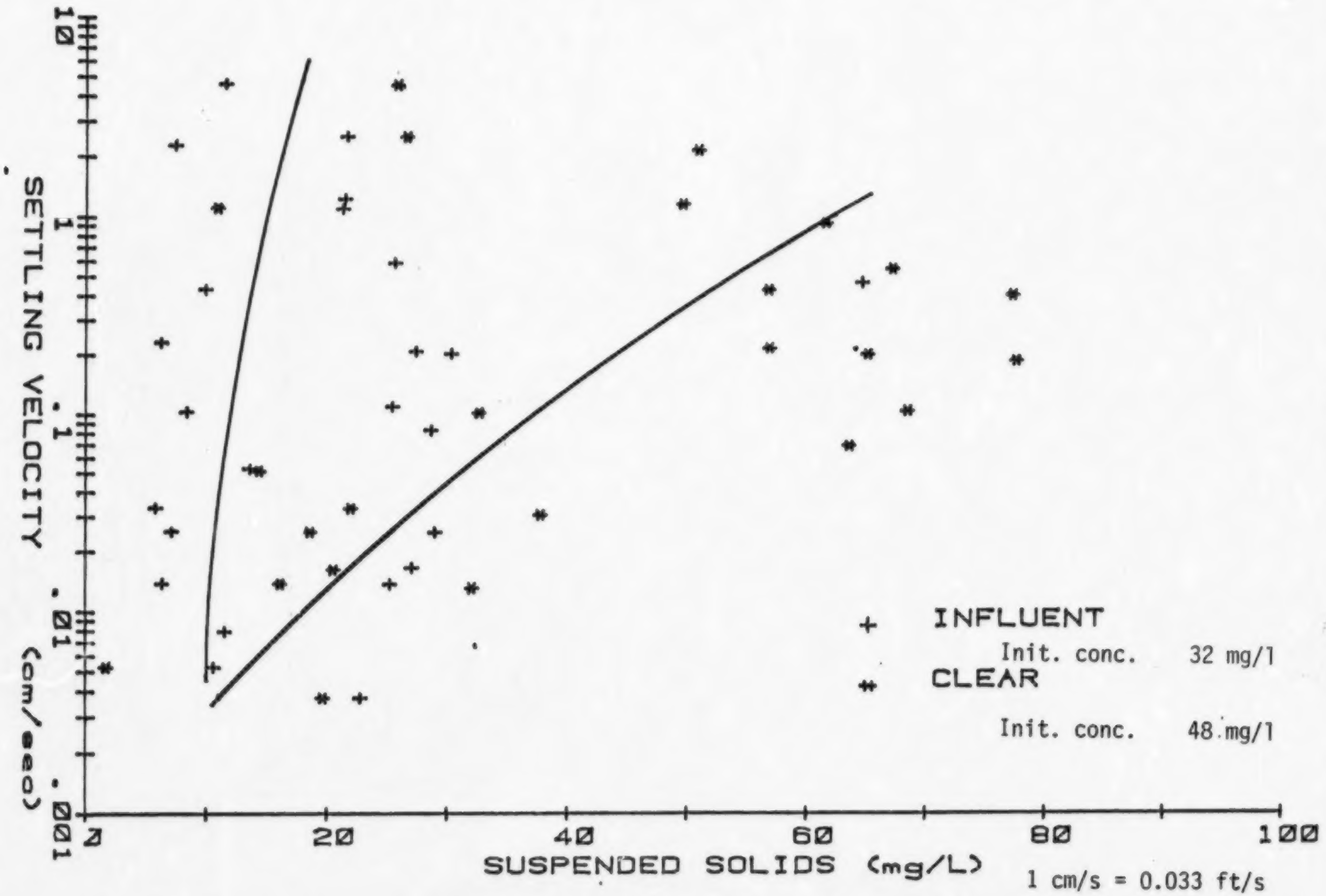
Sampling during the 7/2/81 event required 15 minutes during which time the flow ranged from 20 to 90 cfs (566.4 - 2549 l/s) and averaged 45 cfs (1274 l/s). Based on the constituents of the influent flow as seen in the settleability analysis and the APWA evaluation technique (4), the theoretical efficiency rate would be 30% at 5 cfs (141.6 l/s) and 12% at 40 cfs (1133 l/s). Actual efficiency was found to be 24% and was similar throughout the range of settling velocities. Since the greatest degree of treatment would be expected to occur at the higher settling velocities the cause of treatment remains questionable. Possible causes of irregular results include clear water sample collection at a later time than influent sampling, biased influent sampling in which non-representative amounts of heavy material were collected and the actual flow containing much greater quantities of light material such that even a low fractional degree of removal would result in high overall removal.

Hand sampling for this event consisting of alternately collecting 8 gal (30.3 l) samples from the influent and clear flow streams, precluded error associated with time sequencing. Data review indicates that the mass of solids was not high for the small sized solids eliminating the third possible source of error. The second possibility is quite likely considering the sampling techniques used. During this event the 3 in. (7.6 cm) sample line located at the influent pipe invert was used for sampling. Sample line velocity may have been insufficient to capture heavier particles. At the time when the clearwater discrete sampler obtained samples having solids concentrations similar to those noted at the start of the settleability analysis, the two discrete influent samplers (EDP Cross-Sectional and the Manning) obtained samples averaging 545 mg/l. If the influent sampling technique for methods would have obtained samples with solids concentration equalling 545 mg/l, the overall observed removal would have been 74% at an average flow of 45 cfs



1 cm/s = 0.033 ft/s

Figure 103. Influent and clear suspended solids settling column results, Lancaster Swirl Concentrator/Regulator (7/2/81).



1 cm/s = 0.033 ft/s

Figure 104. Influent and clear suspended solids settling column results, Lancaster Swirl Concentrator/Regulator (7/20/81 am).

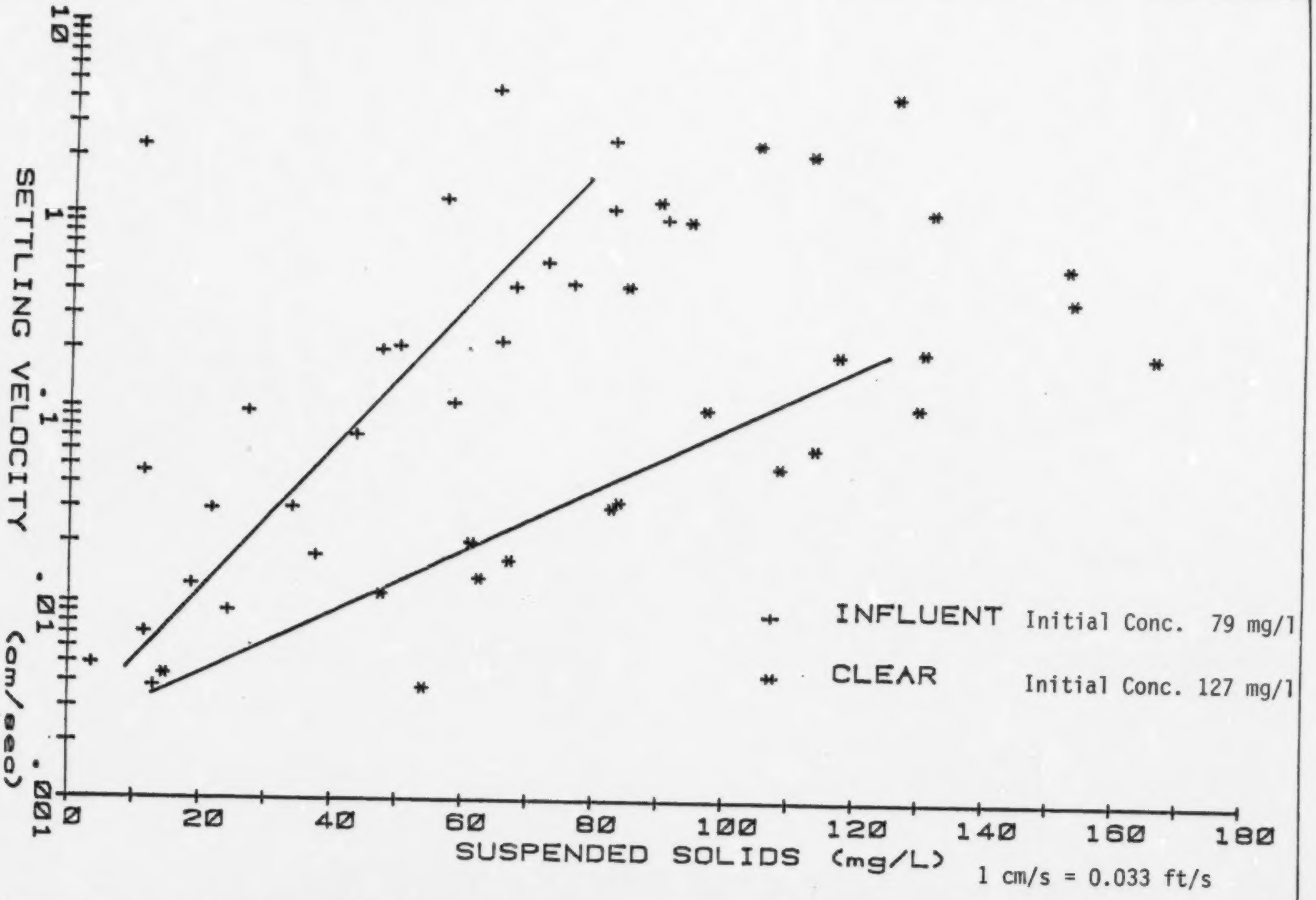
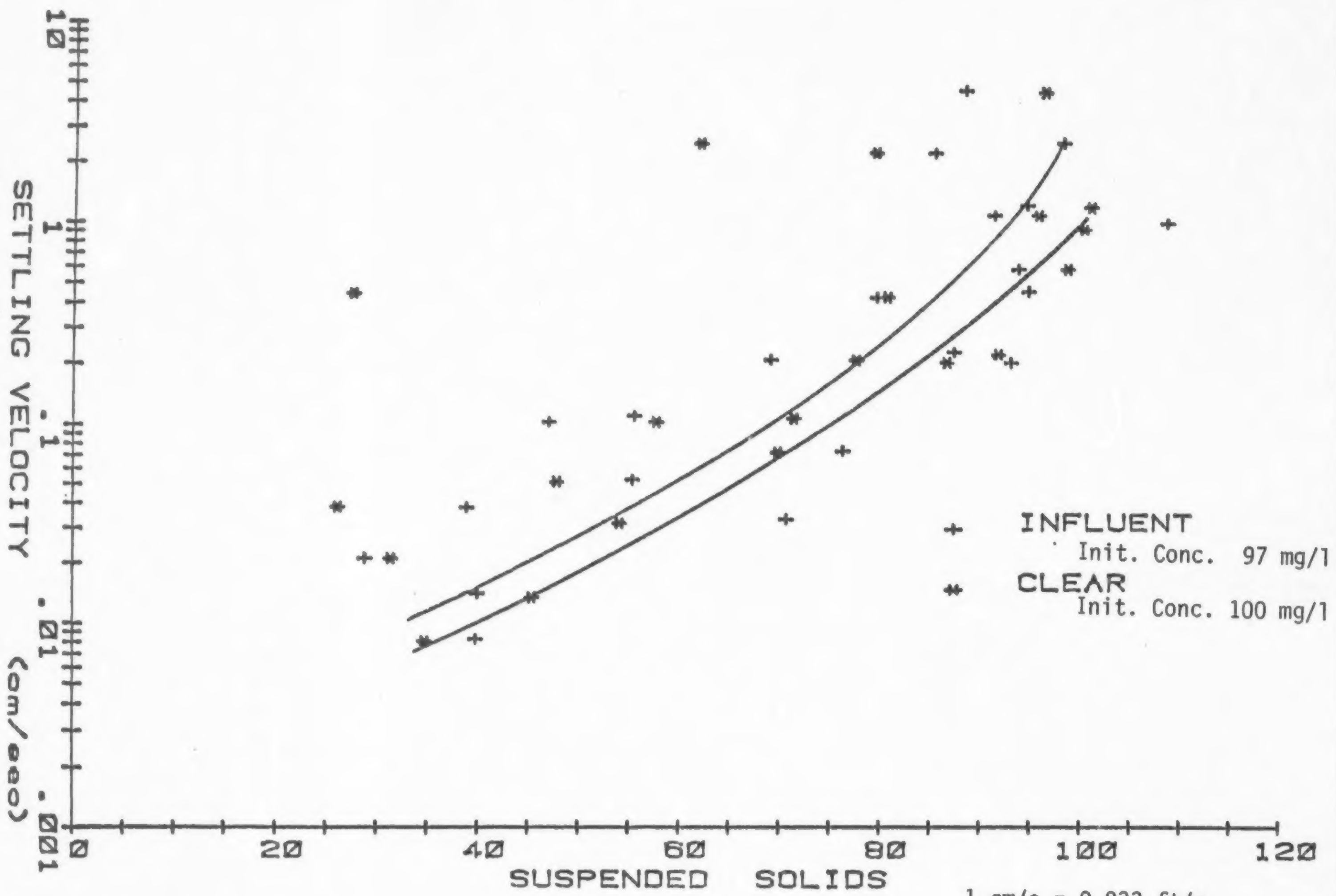


Figure 105. Influent and clear suspended solids settling column results, Lancaster Swirl Concentrator/Regulator (7/20/81 pm).



1 cm/s = 0.033 ft/s

Figure 106. Influent and clear suspended solids settling column results, Lancaster Swirl Concentrator/Regulator (7/28/81).

(1274 l/s) which is reasonable considering the design parameter of 90% removal at design flow of 40 cfs (1133 l/s). The theoretical removals cited above are based on the actual (possibly biased) influent sample.

## Section 12.9 Overview Summary - Swirl Concentrator Performance

A summary of the Swirl Concentrator/Regulator suspended solids performance for 5 events monitored during the EDP evaluation program and reviewed in section 10.5 is presented in Table 16. Estimated removal and efficiency rates associated with the indicated estimated flows are presented in Table 16. These results were derived primarily by inspection of raw data. Overall flow-weighted removal and efficiency calculations are not presented due to the approximate nature of flow measurements. It appears that the Swirl Concentrator/Regulator provided significant suspended solids removal near design flow conditions. Treatment seemed to deteriorate with lower flow rates. With the exception of the 5/10/81 event (removal and efficiency based on influent and foul sampling) efficiency treatment rates exceed 60% for flows in excess of 20 cfs (565.5 l/s). It should be noted that most of the suspended solids noted were settleable inorganic grit matter.

The Swirl Concentrator/Regulator appears to provide approximately the degree of treatment that it was designed for, that is, 90% removal of settleable material at design flow of 40 cfs (1131 l/s). It appears that the performance data is inconclusive to note any relationship between influent rate and efficiency of solids removal.

## Table 16

## Summary of Swirl Concentrator Performance

| Date of Event | Estimated* Flow Rate (cfs) | Removal** % | Efficiency** % | Notes |
|---|---|---|---|---|
| 9/10/80 | 18 | 70 | 62 | a |
| | 7 | 50 | 39 | a |
| 10/2/80 | 50 | 52 | 47 | a |
| | 7 | 46 | 24 | a |
| | 2 | 80 | 5 | a |
| 5/10/81 | 20 | 12 | 5 | b |
| | 8 | 23 | 5 | b |
| | 6 | 35 | 10 | b |
| 7/2/81 | 55 | 76 | 73 | c,d |
| | 20 | 86 | 78 | c,d |
| 7/20/81 pm | 5 | 41 | 11 | c |
| | 46 | 83 | 80 | c |

** Definitions provided in Chapter 11.

Notes

a - influent samples taken using Manning sampler (correctly aligned)
b - based on Manning influent and foul EDP Cross-Sectional sampler results
c - EDP influent Cross-Sectional/Sampler operative efficiency based on settleability results is 24%, however, efficiency would have been 74% if influent discrete sampling concentration results were used.

### 12.10 Degritter Operation Summary

Table 17 details the results of the Swirl Degritter operation during the evaluation period. Minimal amounts of grit were collected during most of the events. The Degritter operation was plagued with constant solids "bridging" problems due to its structural design and lack of internal wash down unclogging systems. Available data are generally estimated values of volume or weight. The grit weighing scale and recorder mechanism frequently failed to operate and combined with the low grit quantities provided no rate of accumulation data.

Just prior to the 7/20/81 PM event the scale and recorder were tested and adjusted for proper recording of moderate grit accumulations. Although the Degritter appeared to operate properly, the grit hopper blew off the scale during high winds and eliminated possible scale readings by the change in weight. Grit accumulated on the scale itself and was later piled-up, measured and sampled for analysis. A representative sample contained 67% moisture, (higher than the average of 56%) and 51% percent volatile, (higher than the average of 38.7%).

Table 17

Swirl Degritter Operation Summary

| Date | Time of Operation Minutes<br>Discrete Sampling | <br>Degritter Operation | Total Grit | | A | B |
|---|---|---|---|---|---|---|
| 8-10-80 | 105 | - | 20 lb | | - | - |
| 9-10-80 | 45 | - | 15-20 lb | | 32 | 14.6 |
| 9-14-80 | 30 | - | - | | 25 | 6.7 |
| 10-2-80 | 261 | - | - | | 70 | 59 |
| 6-2-81 | 41 | - | 1.5 cu ft | | - | - |
| 6-22-81 | 33 | - | - | MID | 47 | 29 |
| | | | | END | 53 | 43 |
| 7-2-81 | 54 | - | 0.4 cu ft | | 72 | 30 |
| | | (sample taken falling from conveyor) | | | | |
| 7-20-81 | | | 0.7 cu ft | | 82.5 | 76 |
| AM | 73 | - | | | | |
| PM | 50 | 160 | | | | |
| HOPPER | | | 5.0 cu ft | | 67 | 51.5 |
| DEGRITTER | | | .22 cu ft | | 6 | 1.7 |

A = % Moisture
B = Volatile

Average Moisture Content = 38.7%
Average % Volatile = 56%

The moisture content is largely dependent upon the time between unit operation and time of sampling as the water content tends to drain to the bottom of the grit pile and out of the hopper. On 7/2/81 the grit was collected as it fell from the conveyor and contained 72% moisture. The volatile percentage is related to the ratio of organic material and inorganic grit. During the 6/22/81 event a mid storm grit sample contained 29% volatile material and an end of storm sample was 43% volatile, indicating a decrease in the organic grit content of the waste stream with storm duration.

Early, mid and late storm samples from an event in July, 1980 (not shown in Table 17) were 23% 38% and 49% volatile, respectively. In addition, the particle size distribution for each sample was determined by sieve analysis followed by volatile determination of each fraction. Sieve results for this storm are included in Table 18. The early-event sample contained the greatest distribution by particle size. Particles within the mid-storm sample were generally larger and the end-of-storm sample was nearly entirely composed of large particles. Early- event sample fractions were typically 20 to 30% volatile indicating mostly inorganic material. Mid-storm sample fractions were more volatile especially among the larger particles. End-of-storm sample fractions were the most volatile averaging 49%.

TABLE 18

Sieve Analysis of Grit From Swirl Degritter

| | Portion of Storm EARLY | MID | LATE |
|---|---|---|---|
| % Moisture | 43 | 56 | 61 |
| % Volatile | 23 | 38 | 49 |

| Sieve No. Size | Percentage EARLY | MID | LATE | %Volatile EARLY | MID | LATE |
|---|---|---|---|---|---|---|
| 8 | 37 | 45 | 56 | 25 | 47 | 49 |
| 16 | 20 | 24 | 23 | 23 | 41 | 51 |
| 30 | 16 | 14 | 13 | 26 | 38 | 60 |
| 50 | 13 | 8 | 5 | 17 | 18 | 46 |
| 100 | 11 | 6 | 2 | 6 | 9 | 12 |
| 200 | 2 | 2 | 1 | 7 | 5 | 8 |
| PAN | 1 | 1 | 0 | 6 | 13 | 0 |

A sample of the accumulated material from the 7/20/81 pm event was determined to have a density, as sampled including air and moisture, of 57.9 lb/ft.$^3$ (0.9 g/cc). Based on the moisture content of 67%, a volatile fraction of 51.5% and assumed specific gravities of 1.2 for volatile material and 2.65 for grit, the removed grit constitutes 56% air, 29.5% water, 7.5% volatile material and 7.05% inorganics on a volume basis. These values can be used to yield a rough indication of the transport volume required for removal of solid waste measured by weight. During the 7/20/81 am event, 0.7 cu ft (198 l) of grit accumulation was estimated. The grit scale recorded approximately 37 lb (16798 g)of material from which the density could be estimated as 53.lb/ft.$^3$ (0.85 g/cc).

It was difficult to determine the overall efficiency of the Degritter on an accumulated grit basis. The quantity of material entering the unit was unknown due to the problems with sample collection and the long term Degritter operation during Swirl draw down. It could not be assumed that all material entering the Swirl not seen in the clear overflow actually entered the Degritter. It was observed that some degree of accumulation of material occurs in the Swirl during operation. Since the final minutes of Swirl tank drawdown bypass the degritter, an unknown quantity of material never enters the unit preventing mass balance determination.

Efficiency evaluation of the Degritter was attempted on a short term basis by comparison of influent and clear overflow pollutant concentrations. This comparison was performed in two ways during the evaluation. First, discrete samples were collected from the Degritter inflow and clear overflow during the period of Swirl operation. Second, during one event short term, large volume samples were collected for settleability analysis.

## Degritter Operation 6/22/81

On 6/22/81 the Degritter operated throughout the storm event from the time the Swirl liquid level reached a depth of 18 in. (45.7 cm) through the sampling period and until the Swirl drained down to 18 in.(45.7 cm) again.

During the first 33 minutes of this period, (see Figure 107) samples were taken using the new EDP Technologies foul flow Cross-Sectional sampler and the Manning degritter clear overflow sampler. Relative suspended solids concentrations of these samples indicated removal efficiencies between 19% to 75% with an average efficiency of 59%. Since the entire liquid flow passes over the clear weir the degritter efficiency and removal rate are equivalent as defined in

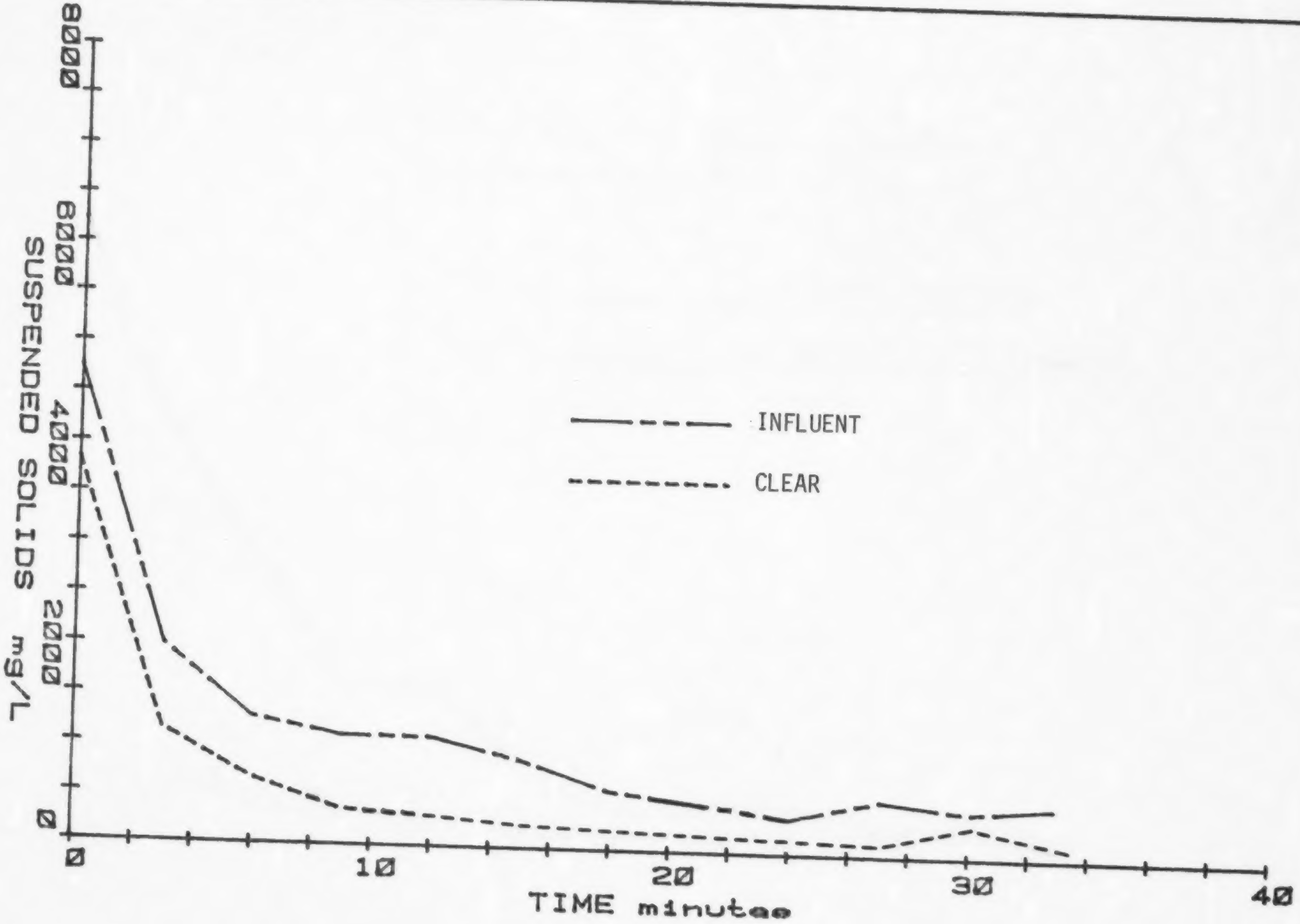


Figure 107. Influent and clear suspended solids conc. vs time, Lancaster Swirl Degritter (6/22/81).

this report. The total mass of solids accumulated during this event was not recorded, nor was the total time of operation since the unit automatically shut down.

Accumulations over the 33 minute period of operation were calculated to be 100 lb (45.4 kg). Mid-storm and end-of-storm samples were calculated to be 29% and 43% volatile, respectively. Based on these measurements and an assumed moisture content of 50% the volume of accumulation during the first 33 minutes could be roughly estimated as 25 $ft^3$ (0.7 $m^3$).

### Degritter Operation 7/20/81

Settleability analysis was performed upon the Swirl Degritter influent and clear overflow streams collected during the 7/20/81 am evaluation. Due to the difficulty in sampling the Degritter clear flow stream the sample volume was limited and an 8 gal (30.3 l) settling column at the Swirl site was used. Procedures for use of this column are detailed in Chapter 11. For the sake of consistency the influent Degritter sample was also tested using the column at Lancaster. Material at the base of the column at the end of the influent sample test was removed for sieve analysis. The results of the sieve analysis were then used to aid the overall evaluation of the degritter performance.

Visual review of the 7/20/81 am data plot (see Figure 108), indicate little or no removals. The Degritter clear overflow concentration of 130 mg/l is slightly higher than the influent concentration of 103 mg/l at the time of initial mix. This phenonmenon was also indicated within sieve analysis results of the material in the base of the column at the end of each test. There were greater amounts of material in the clear sample than in the influent with settling velocities in low velocity ranges.

Review of the sampling procedures used provide a reasonble explanation. The procedure was to hand-sample the clear overflow with a small bucket a sufficient number of times to fill a 4 gal (15 l) container, requiring about 14 minutes per container. Then a 4 gal (15 l) container was filled within 3 seconds with influent sample via a 2 in. (5 cm) valve at the invert of the influent line.

Although this time differential appears minimal the effects on relative concentrations can be substantial. The detention time within the 250 $ft^3$ (7080 l) Degritter at a flow rate of 1.2 cfs (34 l/s) is 167 seconds. Combined with the 1 minute time of sampling the clear samples were actually collected nearly 4 minutes prior to the time of influent flow through. Review of discrete clear samples

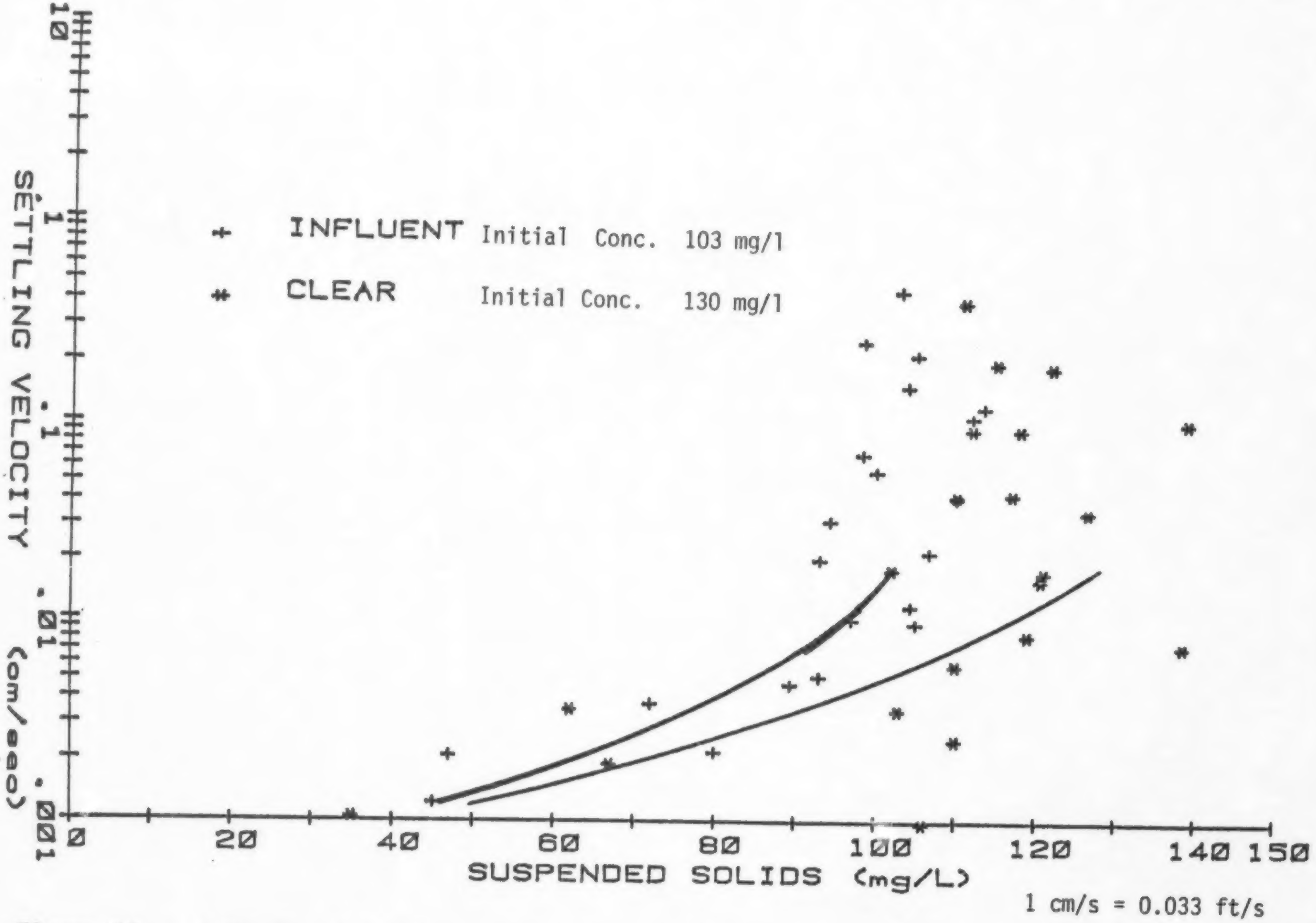


Figure 108. Influent and clear settling column results, Lancaster Swirl Degritter (7/20/81).

indicates a concentration change from 180 to 120 mg/l over 7.5 minutes. The 60 mg/l change over 7.5 minutes implies a 32 mg/l change over the 4 minute delay. This value agrees well with initial concentration discrepancy seen.

On this basis it appears that the unit provided no treatment, however the larger particles revealed during the sieve analysis negates this conclusion. At the end of the influent settling column analysis, the column liquid suspended solids averaged 55 mg/l and 11.9 grams of material were removed from the base of the unit for sieve analysis. As stated the settling column at Lancaster has limited mixing potential. Had the solids fraction above been completely suspended during the initial mix, the influent would have been 452 mg/l. On this basis the removal efficiency of the unit could be estimated using the clear concentration of 130 mg/l to be 71%. This value is based almost entirely on material too large to be captured by the settleability analysis. Considering the time lag calculated above, actual removals could have been higher had removal of smaller particles actually occured.

This high value of removal and the large quantity of large particle grit led to further review of the sampling techniques. Influent samples were collected from a 2 in. (5 cm) port at the invert of the 12 in. (30.5 cm) pipe, one foot downstream of the Hydro-Brake. Although the Hydro-Brake should create complete mix, calculations indicate that up to 6.6 grams of the sieved 11.9 grams could have been non-representative and biased the sample. Based on this the actual influent concentration could be estimated at 187 mg/l, indicating an overall removal of 30%.

Evaluation results for the Swirl Degritter are not conclusive as to its performance. Photographs of grit removed are shown in Figure 109.

## 12.11 LANCASTER DISCOSTRAINER EVALUATION

The Discostrainer is located in the mezzanine area above the basement area. The unit is set up to treat either Swirl influent or foul flow with the selected waste stream pumped from the waste pipe into the Discostrainer. Flow rate is controlled by throttling a valve downstream of the pump.

The intent of the Discostrainer is to remove fine particles from the waste stream. The waste enters a central basin wherein a circular screen assembly rotates on each side. Liquid passes through the screens by gravity flow

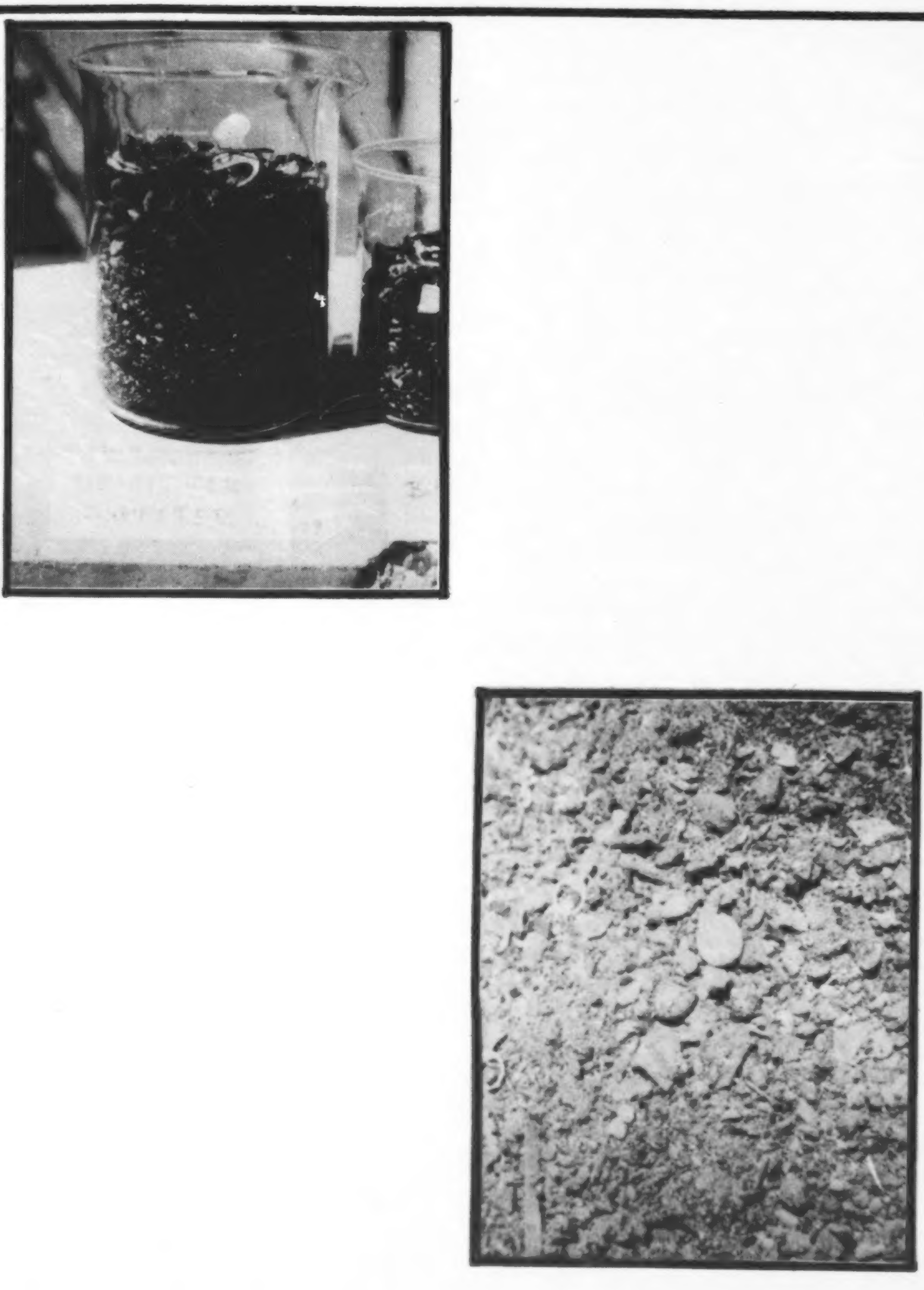


Figure 109. Photographs of grit removed by Swirl Degritter, Lancaster.

leaving particulate matter larger than the screen mesh size on the screen. The screen rotation allows the underwater portion to rise out of the waste stream and pass before a series of backwash jets. Backwashed material falls back into the untreated waste stream. Accumulated debris builds up between the screens and eventually overflows into the screw conveyor from the degritter.

Operation of the Discostrainer has demonstrated that the unit fails to effectively remove the material as predicted. Most observations of the unit operation indicate that this is more due to the method of application than to actual unit efficiency. In the period of 1978-1979, the unit was operated using foul Swirl flow. Due to poor operation of the backwash system the screens became totally clogged. They could not be cleaned and were replaced.

Operation in 1981 indicated that the backwash system continued to clog the spray jets. The backwash system was designed to use tap water rather than treated Discostrainer waste and the clogged jets are the result of fine particles in the waste.

Accumulations within the central assembly of the Discostrainer were minimal for a test conducted on 7/20/81. Only 4 cu in. (65.5 cc) of material were collected during the morning event and on July 28, 1981 only 16 cu in. (262 cc) were removed.

Since the feed to the system is throttled it is likely that only minimal amounts of material were in the influent flow. The material present would have been macerated while passing through the pump. With the pump located on the bottom floor, the pipe rising to the mezzanine undoubtedly settled out much of the larger material.

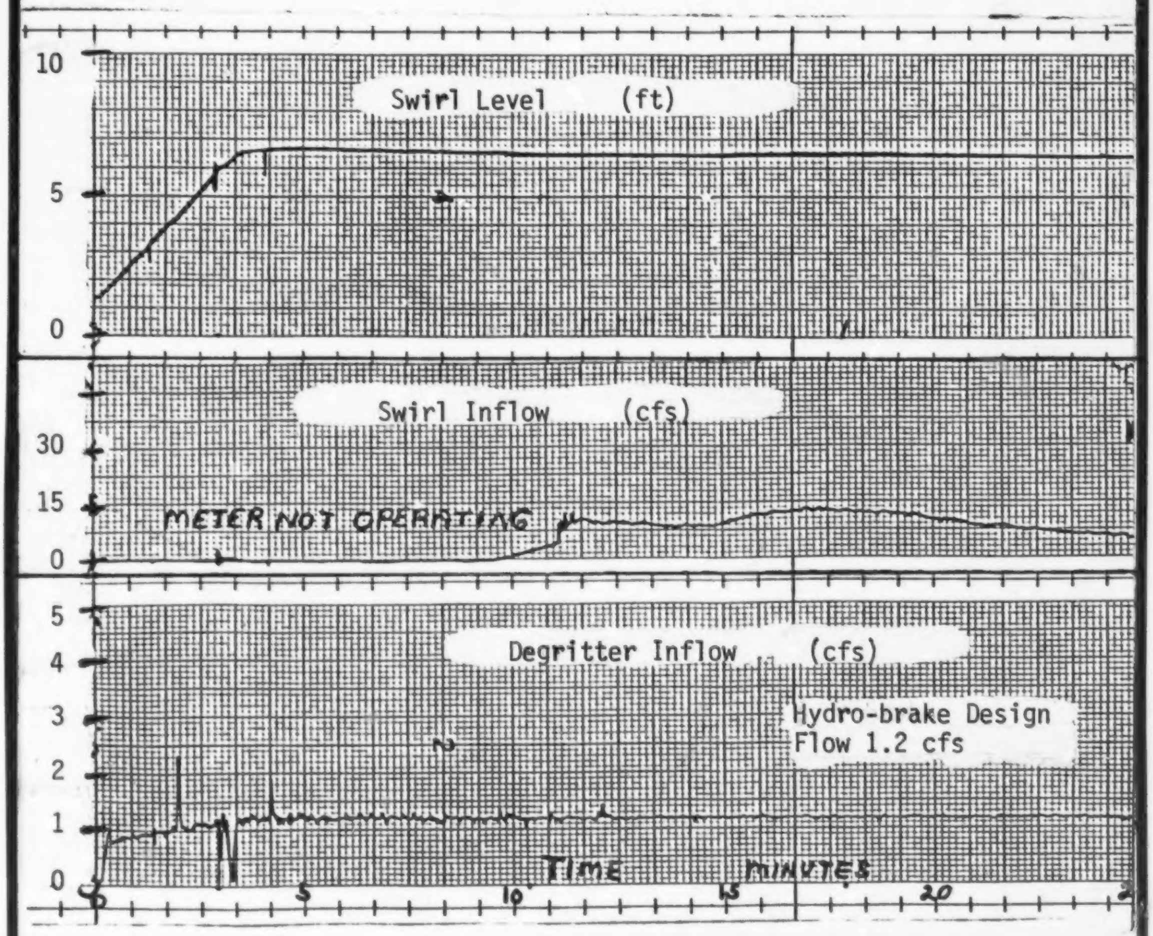
The system as presently operated, fails to demonstrate reasonable removal of material. Proper operation for reliable testing would require setting the unit to receive gravity inflow with no vertical pipe sections for settling and changing the screen backwash system to utilize tap water.

## 12.12 Hydro-Brake

The Lancaster swirl degritter was designed to treat the entire foul flow from the swirl concentrator. At a 3% foul underflow rate this would imply 1.2 cfs (34 l/s) of the 40 cfs (1133 l/s) Swirl design flow. A 12 in. (30.5 cm) underflow line connects the two units and flow control is required along the line. Initially, a pinch valve was utilized coupled to a flow meter. Based on operational problems and the desire to investigate new technologies, the pinch valve was replaced by a Hydro-Brake.

Flow through the 12 in. (30.5 cm) line was recorded using a Fisher-Porter magnetic flow meter, calibrated at a hydraulic testing laboratory prior to installation. A flow record taken during one event with the Hydro-Brake in place is pictured in Figure 110. With only slight variation the unit delivered the design flow throughout the event. At the same time the flow to the swirl considerably varied and the height of backwatering varied substantially as shown in the records in Figure 110.

The Hydro-Brake proved to yield consistant flow throughout each event and required no maintenance during the project. Degritter solids waste often included tin soda cans. There was never a clogging problem with the Hydro-Brake.



1 cfs = 28.3 l/s
1 ft = 30.5 cm

Figure 110. Stripcharts, Hydro-Brake Evaluation.

# CHAPTER 13

## West Roxbury Evaluation

### 13.1 Foreword

This chapter details the results and analysis of the Swirl and Helical Bend Regulator/Concentrator operations at West Roxbury, Mass. Section 13.2 contains a chronology of events during the evaluation and details operational problems and solutions and field/analytical data for each event. Section 13.3 presents individual event results which demonstrate the effectiveness of the units for stormwater treatment. Results of several settleability analysis are described in section 13.4. Summary performance results are presented in section 13.5. Section 13.6 presents the results of various dye studies performed during the evaluation period.

### 13.2 Evaluation Overview

The following chronological summary highlights the major activities during the West Roxbury evaluation.

| DATE | UNIT | ACTIVITY |
|---|---|---|
| 11/26/79 | Swirl | Samples Collected Solids, COD Tested |
| | Helical | Samples Collected Solids, COD Tested |
| 4/4/80 | Swirl | Samples Collected Solids, COD Tested |
| 4/10/80 | Swirl | Samples Collected Solids, COD Tested |
| 5/8/80 | | Monitoring Initiated Insufficient runoff for sampling |
| 6/29/80 | Swirl | Samples Collected Solids, COD, TP Tested |
| | Helical | Samples Collected Solids, COD, TP Tested |
| | | Influent Column Test - Settleability |
| 7/8/80 | Swirl | Insufficient runoff to operate unit |
| 7/16/80 | | Monitoring Initiated Insufficient Runoff |
| 7/29/80 | Swirl | Samples Collected Solids, COD Tested |
| | Helical | Samples Collected Solids, COD Tested |
| 8/11/80 | | Monitoring Initiated Insufficient Runoff |

| | | |
|---|---|---|
| 8/15/80 | | Monitoring Initiated Insufficient Runoff |
| 8/30/80 | | Begin pipe sleeve installation |
| 9/16/80 | | Complete pipe sleeve installation |
| 9/26/80 | | Monitoring Initiated Insufficient Runoff |
| 10/3/80 am | | Monitoring Initiated Insufficient Runoff |
| 10-3-80 pm | | |
| | Swirl | Samples Collected Solids, COD Tested |
| | Helical | Samples Collected Solids, COD Tested |
| | | Influent Column Test - Settleability |
| 10/18/80 | | Monitoring Initiated Insufficient Runoff |
| 10/25/80 | Swirl | Samples Collected Solids, COD Tested |
| | Helical | Samples Collected Solids, COD Tested |
| | | Influent & Foul Effluent Column Test-Settleability |
| 11/18/80 | | Snow |
| 11/28/80 | | Monitoring Initiated Insufficient Runoff |
| 12/10/80 | | Snow |
| 12/14/80 | | Snow |
| 5/12/81 | | Monitoring Initiated, Insufficent runoff for sampling |
| 5/14/81 | | Begin pipe sleeve alterations; V-Shape |
| 5/20/81 | | End pipe sleeve alterations |
| 5/28/81 | | Monitoring Initiated, Insufficient runoff for sampling |
| 6/9/81 | Swirl | Samples Collected Solids, COD, Bacteria Tested |
| | Helical | Samples Collected Solids, COD Tested |
| | | Swirl Influent & Clear Settling Column Test |
| 6/22/81 | Swirl | Samples Collected, Solids, COD Tested |
| | Helical | Samples Collected Solids, COD Tested |
| | | Swirl Influent & Clear, Helical Clear Settling Column Test |

| | | |
|---|---|---|
| 6/25/81 | | Monitoring Initiated, insufficient runoff for sampling |
| 7/29/81 | | Monitoring Initiated, minimal runoff, limited sampling |
| 8/4/81 | Swirl | Samples Collected Solids Tested |
| | Helical | Samples Collected Solids Tested |
| | | Swirl Influent & Clear, Helical Clear Settling Column Test |

### Summary of Events Data

The following is a description of the storm events monitored atthe West Roxbury site. Performance data is briefly described. Those events demonstrating good performance and facility operation are discussed in greater detail in section 13.3.

### Event: 11/26/79

The pre-storm event consisted of light rain during most of the early morning hours with a total accumulation of 0.12 in. (3mm) over a 12 hour period. The actual sampled event was characterized by moderate to heavy downpour resulting in records indicated an antecedent dry period of over a week with no measurable amounts of rainfall.

The Swirl and Helical Bend Concentrator/Regulator were operated simultaneously. Samples were collected manually at the influents, clear overflows and foul underflows. Flow in the Swirl ranged from 0.18 to 1.19 cfs (5.1 to 33.7 l/s). In the Helical Bend flow varied from 1.20 to 1.53 cfs. (33.9 to 33.7 l/s).

Swirl samples selected for analysis included 7 influent, 6 clear overflow and four foul effluents. Parameters tested were TSS, VSS, settleable solids, volatile settleable solids and COD. The Helical Bend samples included 3 influent, 2 clear overflows and 2 foul effluent. Samples were analyzed for TSS, VSS, settleable solids, volatile settleable solids and COD.

### Event: 4/4/80

This storm event was characterized by moderate rain over a 70 minute period. The antecedent period consisted of a dry day, one day of light rain followed by a dry day immediately prior to the storm event evaluated.

Twenty six samples were collected from Swirl influent, 20 from clear overflow and 29 from the foul underflow. Flow during sampling ranged from 0.23 to 2.3 cfs ( 6.5 to 65 l/s). Samples were analyzed for TSS, VSS, settleable solids volatile settleable solids and COD. A dye study was performed during this event to observe flow patterns within the Swirl.

### Event: 4/10/80

This event was characterized by medium rain for a 2 hour period resulting in a total accumulation of 0.2 in. (5 mm). The antecedent period consisted of 3 dry days and 2 days of trace precipitation immediately prior to the event.

Samples were collected manually from the Swirl at 5 minute intervals. A total of 79 samples were taken: 27 influent, 20 clear and 32 foul samples. Flow through the unit during sampling ranged from .55 to 1.1 cfs (15.5 to 31.1 l/s). Samples were analyzed for TSS, VSS, settleable solids, volatile settleable solids and COD. Removal results are discussed in detail in section 13.3.

### Event:6/29/80

The storm event was characterized by 0.16 in.(4 mm) of rain in a 50 minute period. The antecedent period consisted of 7 dry days and one day of trace precipitation prior to the event.

Samples were collected manually from the Swirl influent/ clear/ foul and Helical Bend influent at intervals of approximately 5 minutes. 43 samples from the Swirl included, 14 influent, 9 clear, 19 foul and 1 floatables sample. 44 samples from the Helical Bend included, 14 influent, 8 clear and 21 foul with one special floatables sample taken from the unit.

Influent settling column samples were collected immediately following the start of rainfall within the first 15 minutes of the sampling program.

Flow in each unit during the event averaged .88 to 3.5 cfs (24.9 to 9 l/s). Samples were analyzed for TSS, VSS, settleable solids and volatile settleable solids.

### Event: 7/29/80

This storm event was characterized by a period of moderate rain, resulting in a total of 0.43 in. (11 mm) over a 36 hour period. The antecedent dry period was 5 days.

Sampling began on the Swirl using both manual grab sampling and Manning automatic samplers. Automatic samples were taken at Swirl influent and foul flow at 3.75 minute intervals. Manual sampling of Swirl clear, Helical Bend clear, Swirl influent, Helical Bend foul and Swirl foul were coordinated with automatic samplers. Floatables samples were also taken early in the storm event.

Flow into the Swirl unit ranged from .44 to 4.7 cfs (12.5 to 133 l/s) during sampling. A total of 52 samples were collected from both units, including 11 Swirl influent (3 automatic and 8 manual), 5 Swirl clear (manual), 11 Swirl foul (9 automatic and 2 grab) along with 2 foul drawdown samples taken after unit shut down. Five Helical Bend clear samples were taken manually and 18 foul samples were collected automatically, 11 of which were drawndown samples. A dye study was conducted on the Swirl to note flow patterns.

Sediment had collected at the bottom of the Helical Bend covering an area approximately 7 in. (18 cm) wide by 0.125 in. (0.6 cm) deep throughout the length of the unit. Samples were taken and analyzed for TSS, VSS, settleable solids and volatile settleable solids.

## Event: 10/3/80

The storm event was characterized by light rain over a 20 hour period prior to the sampled event. The antecedent dry period was 4 days. Heavy rain began at 12:30 pm resulting in a total accumulation of 0.16 in. (4 mm). The Swirl operation began with sampling of Swirl influent, foul effluent and clear overflows.

Manning automatic samplers were used for Swirl influent and foul effluent at 3.75 minute intervals. Clear overflow samples were taken manually in 1-l bottles. Manual grab samples were also taken of Swirl influent. Flow into the Swirl varied from 0.01 to 6.3 cfs (0.3 to 178 l/s) during this event. After two minutes into the sampling event the Swirl foul became backwatered and the influent gates were shut down. At this time the Helical Bend was turned on. Operation of the Helical Bend was possible due to the elevated position of the Helical Bend foul discharge over the swirl foul discharge. Helical Bend samples were taken manually every 3 minutes for influent, clear and foul. The Helical Bend was shut down at 2:35 pm and the Swirl was then operated for the collection of discrete and settling column samples. During sampling flow levels in the unit ranged from 3.76 cfs to 5.2 cfs (106.4 l/s to 147.2 l/s)

Fifteen influent, 22 clear and 14 foul samples were taken from the Swirl unit. Twelve influent, 20 clear and 12 foul samples were collected from the Helical Bend. Samples were analyzed for TSS, VSS, settleable solids, volatile settleable solids and COD. Influent settling column samples were collected and settling column test was performed for this event.

## Event: 10/25/80

The storm event was characterized by 3.5 hours of moderate rainfall with a maximum 15 minute intensity of 0.48 in./hr (12 mm/hr) and a total accumulation of 0.54 in. (14 mm). Antecedent dry period was 6 days. Approximately 1 hour after rain began, flow entered the Swirl and Helical Bend units. Influent and foul flow sampling was then initiated. After one-half hour, the units were full and clear overflow sampling commenced.

Mechanical problems limited the pumpage from the foul sump tank and the Swirl operation was temporarily ceased. The Helical Bend unit operation continued for another 45 minutes, at which point influent to the Helical Bend was shut off and the Swirl placed on-line. The Swirl unit was then operated for one-half hour.

A total of 59 samples were collected during the Swirl operation and 39 samples were collected during the Helical Bend operation. Influent, Swirl foul , and Helical Bend foul effluent samples were collected for settleability analysis. During sampling flow ranged from .27 to 4.5 cfs (7.6 to 127 l/s) in the Swirl and 0.27 to 4.3 cfs (7.6 to 122 l/s) in the Helical Bend. All samples were analyzed for TSS, VSS, settleable solids, volatile settleable solids and COD. Settleability samples were analyzed for TSS and VSS.

## Event: 6/9/81

On June 9, 1981 a light rain occurred throughout the morning at a rate of 0.1 in./hr (2.5 mm/hr). Between noon and 1 pm 0.25 in. (6.4 mm) of rain fell and the Swirl and Helical Bend were operated for an hour. The antecedent dry period was 2 days. Samples were collected from the Swirl and Helical Bend influent, clear flows and foul flows for discrete analysis. Samples were also taken from the influent and clear flows of both units for settleability analysis.

Thirteen influent, 13 clear and 17 foul samples were collected from the Swirl and 10 influent, 9 clear and 15 foul samples were collected from the Helical Bend. All samples were analyzed for VSS, TSS, settleable solids, volatile setleable solids and COD. Several influent and clear Swirl samples were analyzed for Total Coliforms. No bacterial removal was noted.

## Event: 6/22/81

On June 22, 1981 a heavy thunderstorm occurred amounting to 0.4 in. (10 mm) of rain. The antecedent dry period prior to this event was 6 dry days. The Swirl and Helical Bend were operated simultaneously until problems arose with the Swirl operation and the unit was temporarily shut down. For this event a screen assembly was placed in the Swirl clear overflow downtube to collect any debris passing over the clear weir. The clear overflow screen assembly filled with floatables material to the extent that the screen clogged. Since it was impossible to remove the screen with the unit on-line, the Swirl influent was stopped and the screen assembly pumped dry.

During this time the Helical Bend was operated after a slight initial delay while evaluating the Swirl condition. The Helical Bend was successfully operated for 1 hour and influent, clear overflow and foul underflow samples were collected along with composite samples for settleability analysis of the influent and clear overflow. After terminating the operation by closing the influent gates, drawdown samples were collected in the foul flow for an additional 14 minutes.

The Swirl unit was placed back on line and run simultaneously with the Helical Bend for 19 minutes. Swirl operation continued after Helical Bend shutdown for a total operation time of 33 minutes plus 30 minutes of downdraw. Influent, clear overflow, foul underflow, clear samples for settleability analysis were collected. Eleven influent, 10 clear and 12 foul samples were collected from the Swirl unit and 12 influent, 12 clear and 12 foul samples were collected from the Helical Bend during this event. Flow in the Swirl ranged from 1.5 to 2.6 cfs (42 to 74 l/s) and 1.5 to 10 cfs (42 to 280 l/s) in the Helical Bend. A dye study was performed on both units to visually observe flow patterns.

## Event: 7/29/81 Storm

Rain showers were moderate to heavy. En route to the site showers were light with a short period of heavy downpour. The streets were relatively clean. Upon arrival at the site the rain had stopped and the units were turned on and began filling. The stormwater was dark grey and heavily laden with quarry dust. Floatables were minimal and consisted mainly of leaves, grass and seeds. Grab samples of Swirl influent and clear and Helical Bend clear were collected . Automatic Swirl foul and Helical Bend foul samplers each collected 20 samples. As the units emptied the bottoms of both were covered with fine dark grey sediment, presumably quarry dust.

## Event: Summary 8/4/81

This storm event was characterized by a heavy downpour lasting approximately 35 minutes resulting in a total accumulation of 0.86 in. (22 mm). The antecedent dry period was 5 dry days. Sampling began 15 minutes after the start of the event with Swirl and Helical Bend influent and flow samples along with influent samples for settling column analysis. Sixteen minutes into the event clear overflow began over the units and samples were collected. Samples were collected manually for Swirl and Helical Bend clear flows and for influent and clear settling column samples taken. Automatic samplers were used for the collection of Swirl influent and foul samples and Helical Bend foul samples at 3.75 minute intervals.

Eleven influent, 12 clear, 20 foul and 3 tank samples from the Swirl unit were analyzed for TSS, VSS, settleable solids, volatile settleable solids and COD. 11 clear and 18 foul samples from the Helical Bend were analyzed for the same parameters. Influent samples were not collected from this unit during this event.

Settling column analysis was performed on samples taken from the Swirl influent/ clear and Helical Bend clear overflow locations. Samples were collected during the initial 20 minutes of the storm event and were analyzed for TSS and VSS.

A dye study was performed on the Swirl unit during the storm event. Flow during the sampling period ranged from 0.7 to 12.3 cfs (19.8 to 348 l/s) in the Swirl. Flow increased to 12.3 cfs (348 l/s) during first 10 minutes of operation. Similar flows were observed in the Helical Bend.

A mass solids analysis was also performed on the Swirl unit. A sample of solids remaining on the bottom of the unit following the event were quantified and compared with solid concentrations of liquid samples taken during the event. Tank solids accumulations at various stages of the storm event were estimated.

## 13.3 Detailed Event Analysis

Seven storm event data sets were selected for detailed analysis to demonstrate the efficiency of the test devices or display any other event occurances relevant to the evaluation. The events discussed in detail include: 6/29/80, 7/29/80, 10/3/80, 10/25/80, 6/9/81, 6/22/81 and 8/4/81. Removal rate and efficiency results are calculated using methods outlined in section 11.3.

Although both suspended and settleable solids were determined during the evaluation program suspended solids is considered as the prime parameter to assess removal performance for the following reasons. In the settleability test a sample is allowed to settle for 1 hour and then the supernate is sampled to determine non-settleable solids. Settleable solids are calculated based on suspended solids and non-settleable solids estimates. This one hour test bears no relation to the Swirl or Helical Bend efficiency since the solids fractions removed are not comparable. The maximum depth within the sample settling vessel from which the supernate sample is collected was typically four in. (10 cm) . Given a one hour specified settling time the supernate would be expected to capture no particles with settling velocities greater than 0.01 ft/sec (0.003 cm/sec). Since the Swirl is roughly expected to remove 100 percent of particles with settling velocities greater than 0.15 ft/sec (5 cm/sec.) and few particles with settling velocities less than 0.0075 ft/sec (.25 cm/sec.) the results of the settleable solids test are not significant.

Pollutant concentration vs time plots are presented for nearly all events and solids type. Plot of mass removals are not included since overall removal and efficiency rates for both units were not high.

### 6/29/80 Results Summary

Swirl influent, clear and foul sewer time vs concentration plots of suspended solids, volatile suspended solids, settleable solids and volatile supsended solids are presented in Figures 111 through 114 respectively, for the 6/29/80 storm event. Shadings are noted on each plot to denote both positive and negative solids treatment removals. Discharge vs time plots are included on each figure. Similar time vs concentration plots of suspended solids, volatile suspended solids and settleable solids are presented in Figures 115-117 respectively for the Helical Bend Regulator.

Influent solids concentrations fluctuated sharply creating periods of removal and negative removal in comparison

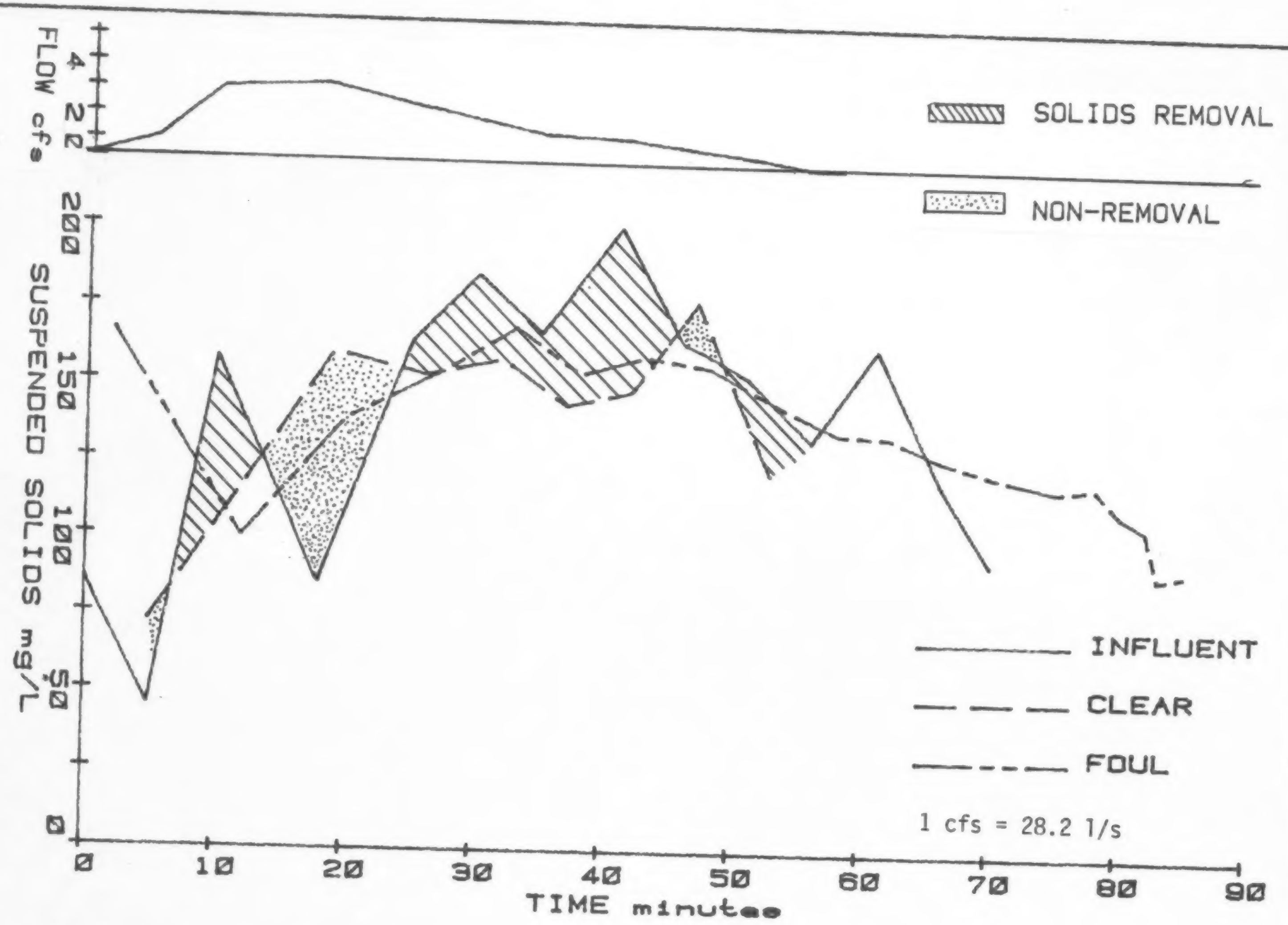


Figure 111. Suspended solids concentrations vs time, W. Roxbury Swirl Concentrator/Regulator (6/29/80).

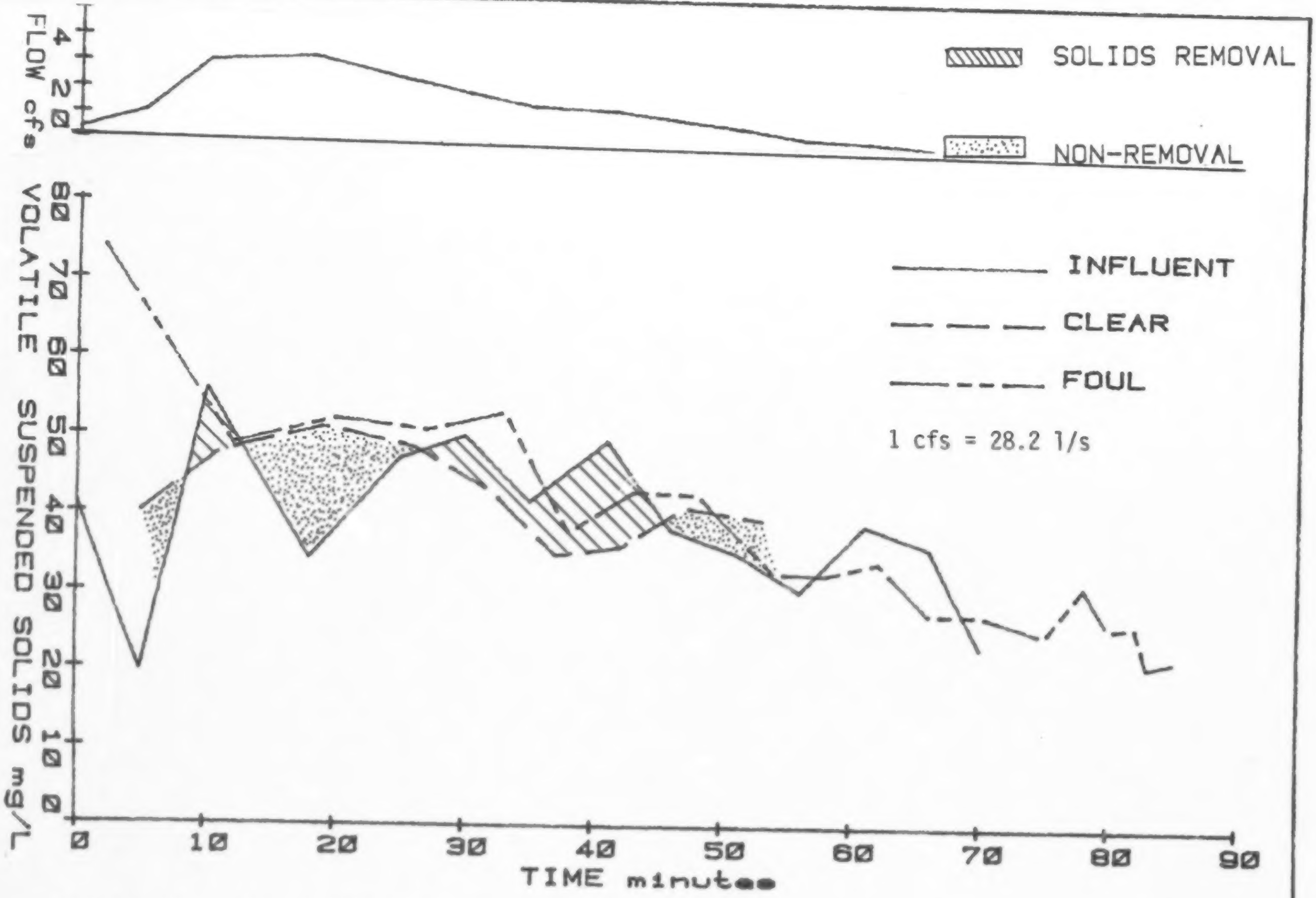


Figure 112. Suspended solids concentrations vs time, W. Roxbury Swirl Concentrator/Regulator (6/29/80).

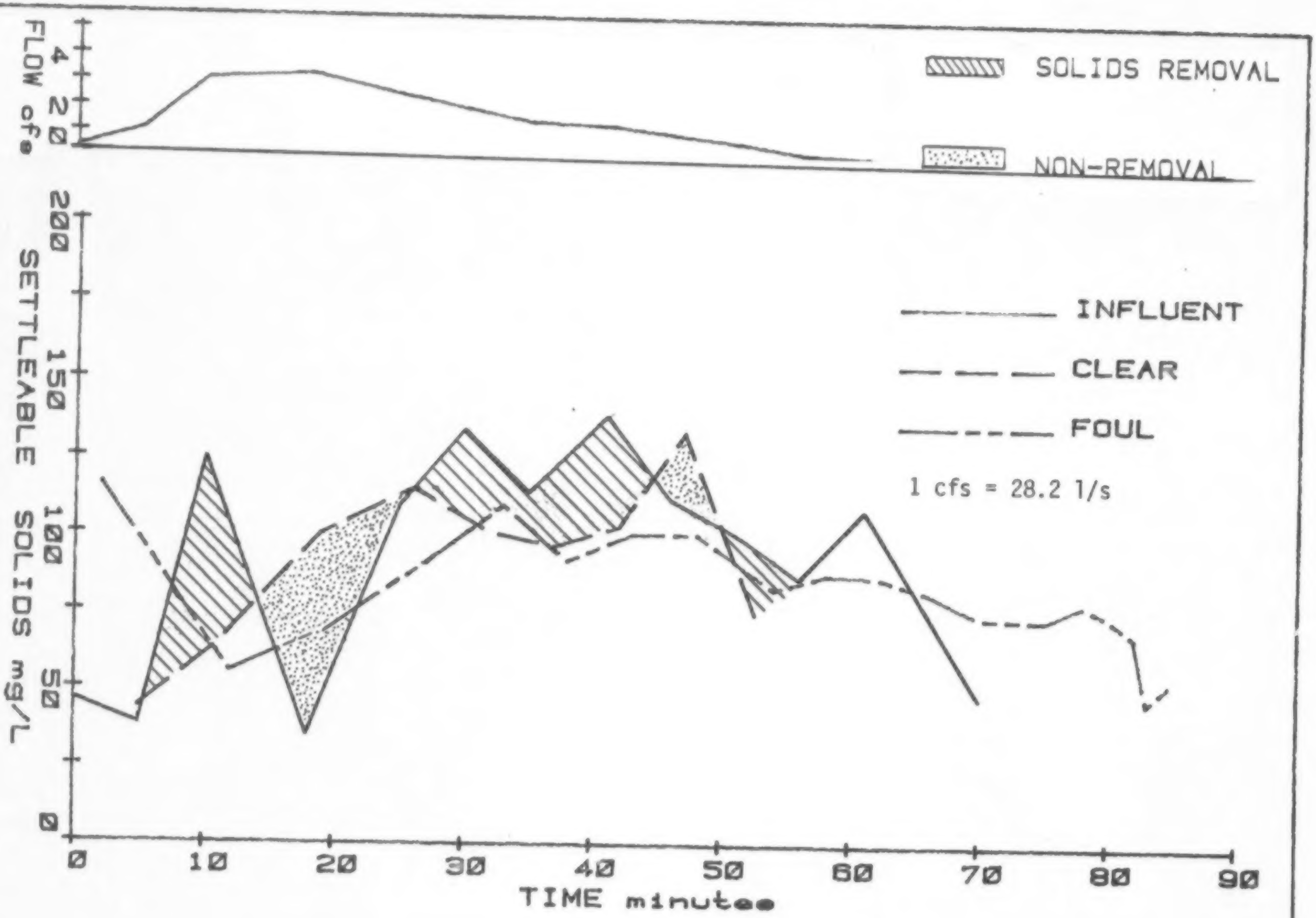


Figure 113. Settleable solids concentrations vs time, W. Roxbury Swirl Concentrator/Regulator (6/29/80).

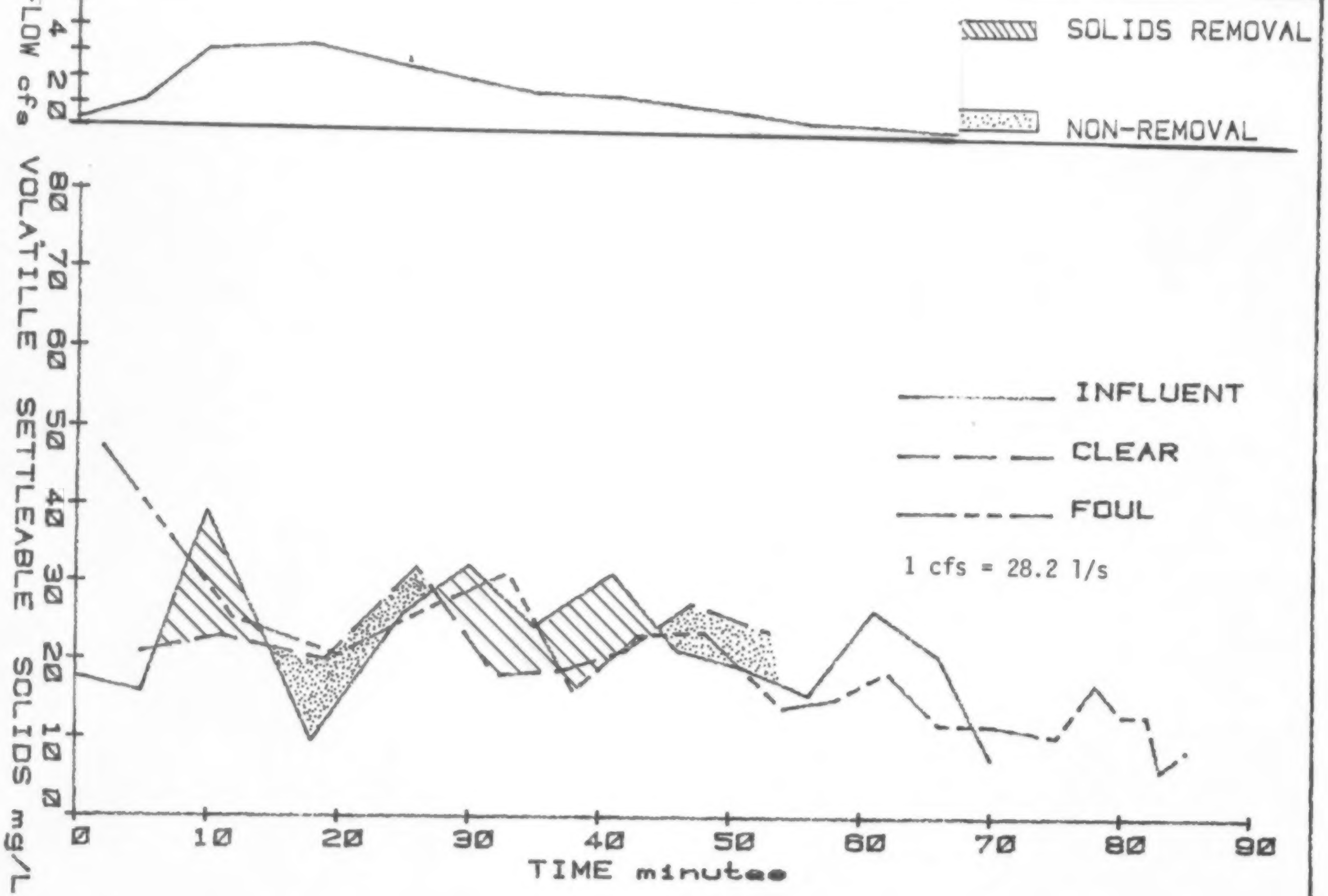


Figure 114. Volatile suspended solids concentrations vs time, W. Roxbury Swirl Concentrator/Regulator (6/29/80).

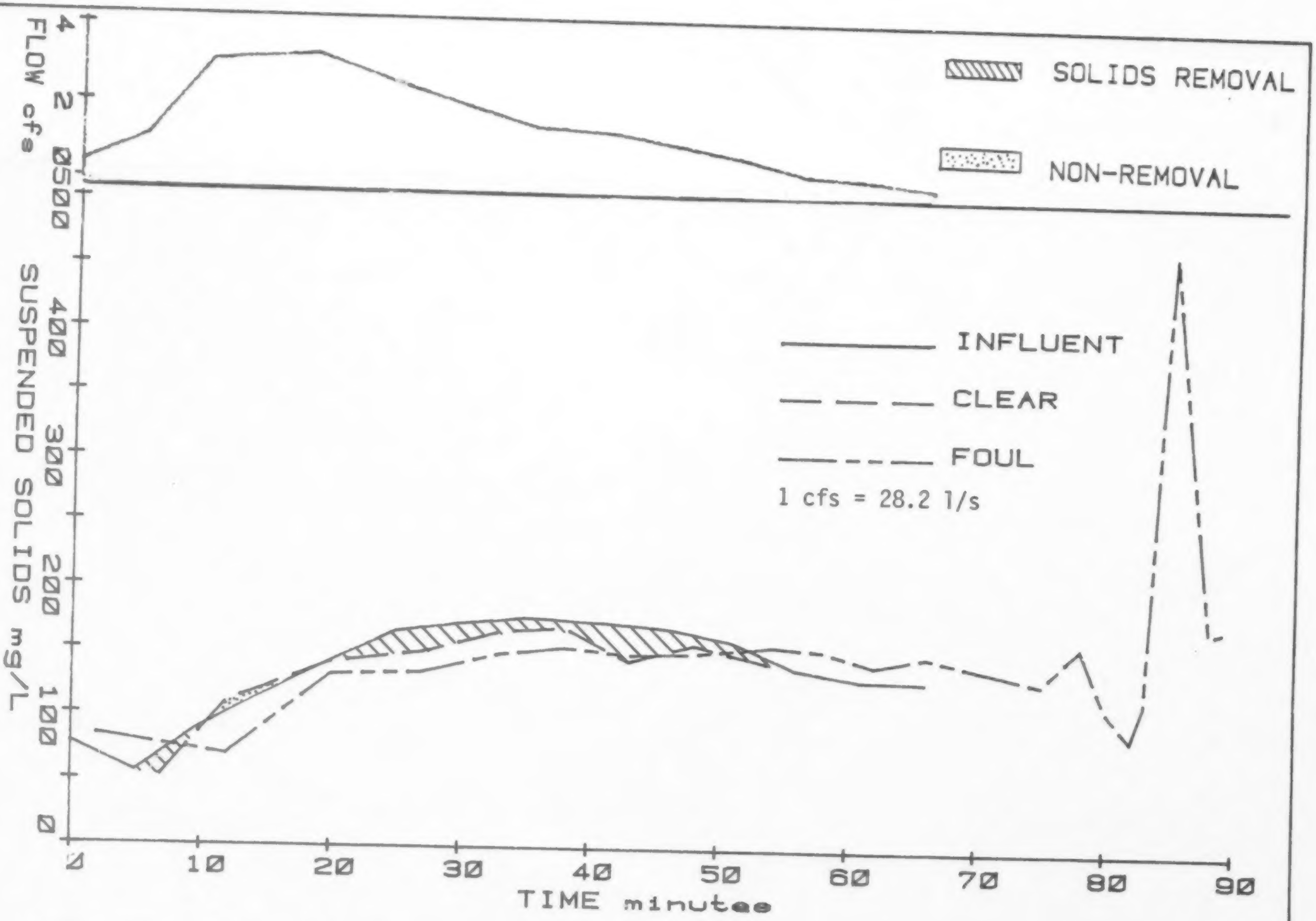


Figure 115. Suspended solids concentrations vs time, W. Roxbury Helical Bend Regulator (6/29/80).

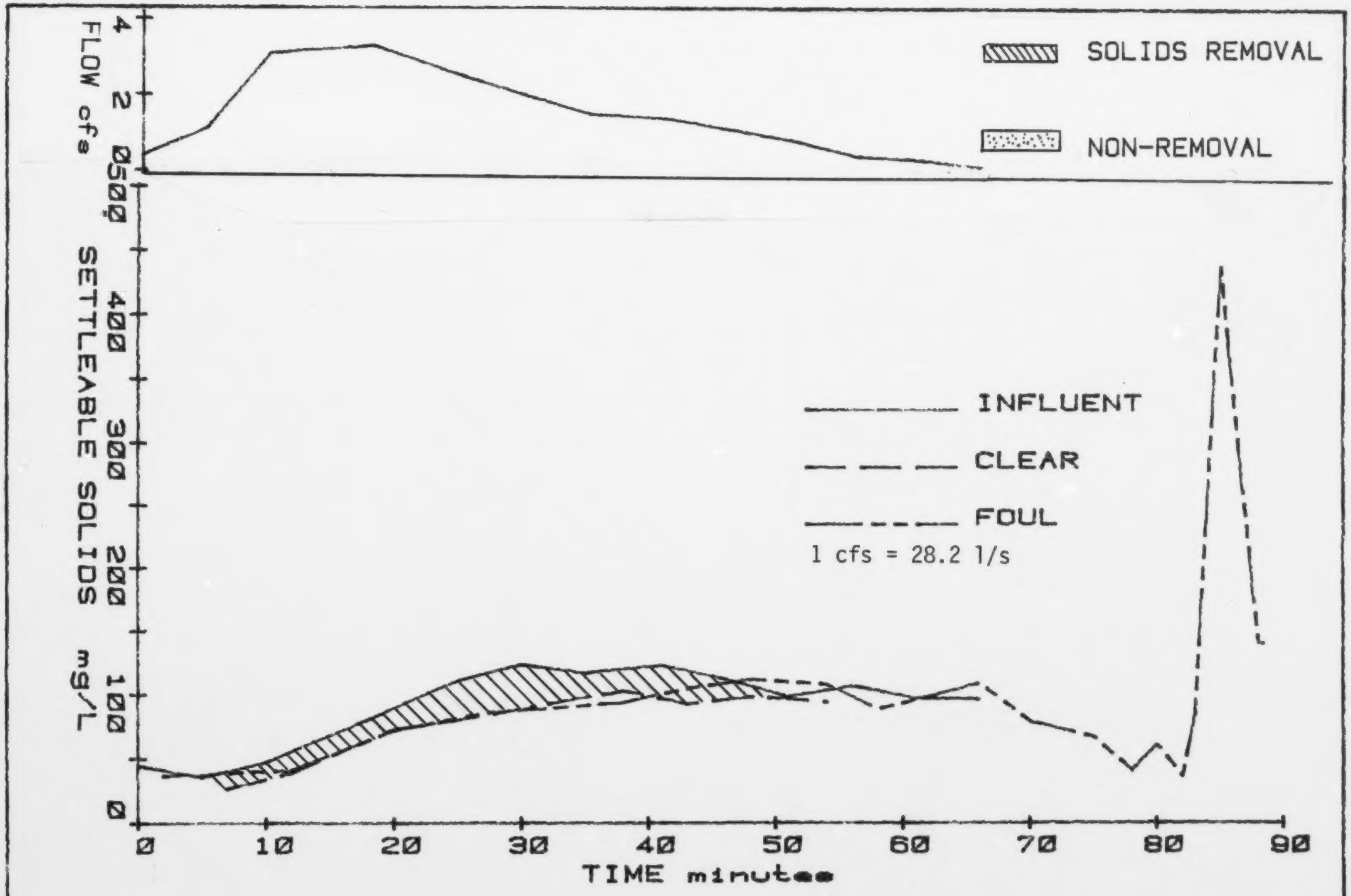


Figure 116. Settleable solids concentrations vs time, W. Roxbury Helical Bend Regulator (6/29/80).

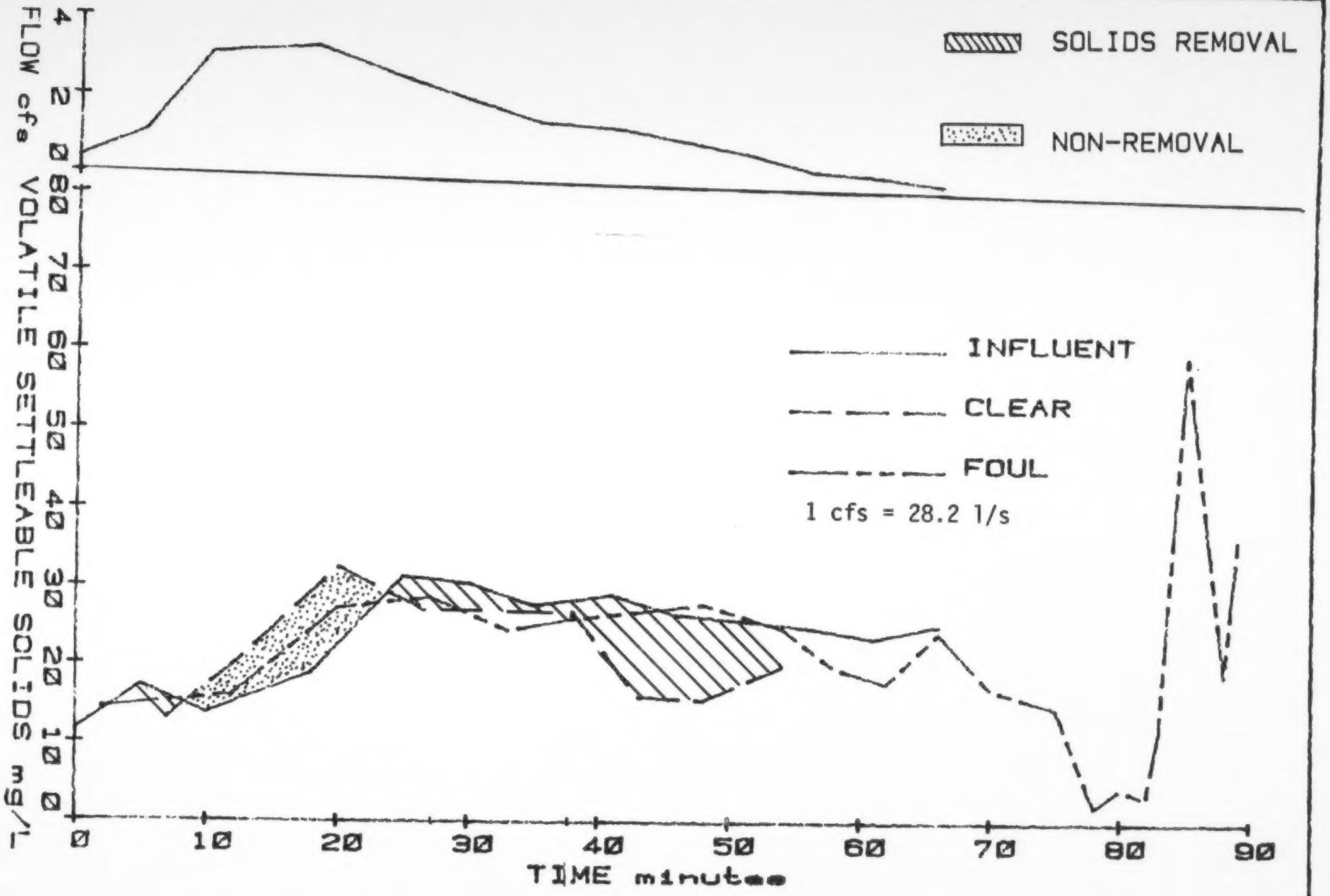


Figure 117. Volatile suspended solids concentrations vs time, W. Roxbury Helical Bend Regulator (6/29/80).

to Swirl clear overflow sample concentrations. Overall the data indicated an average of 21% removal rate for the Swirl. At an influent rate of 2 cfs, (56.6 l/s) the Swirl efficiency rate was 8.2%.

Helical Bend removal and efficiency rates averaged 23% and 6% over a 30 minute period with flow between 1 and 2 cfs. (28.3 and 56.1 l/s)

## 7/29/80 Results Summary

Plots of time vs pollutant influent, clear and foul sewer concentrations of suspended solids, volatile suspended solids, settleable solids and volatile settleable solids are presented in Figures 118-121, respectively for the Swirl concentrator and in Figures 122-125 respectively for the Helical Bend Regulator.

During this event influent samples were collected manually and by automatic samplers for comparative analysis. The automatic sampler intake was located at the invert of the influent pipe. Hand samples were taken throughout the depth of flow. The first hand sample contained heavy solids, floatable organics. The automatic sample failed to include this material. Thereafter the automatic sampler indicated influent solids to be much higher than manual sample values. Volatile fractions were similar for the two techniques indicating the excess material to be inorganics. Based on the location of the intake it can be assumed that heavy materials settled and moved along the base of the pipe, biasing the automatic sampler results to be somewhat higher than manual grab values. Efficiency shadings are not shown on Figures 118-125 due to differences in influent sampling techniques.

Swirl Removal and efficiency rates averaged 35.3% and 27.5% respectively during 10 minutes of clear sampling. Prior to this negative removal results were indicated due to a single high clear solids concentration value. The sample was highly organic and probably contained floatable material remaining from the period of high influent floatable materials.

The Helical Bend demonstrated average removal and efficiency rates of 36% and 2% respectively over a ten minute period as the flow increased from 1 to 4 cfs (28.3 to 113 l/s).

## 10/3/80 Results Summary

Plots of time vs influent, clear and foul sewer pollutant concentrations of suspended solids, volatile suspended

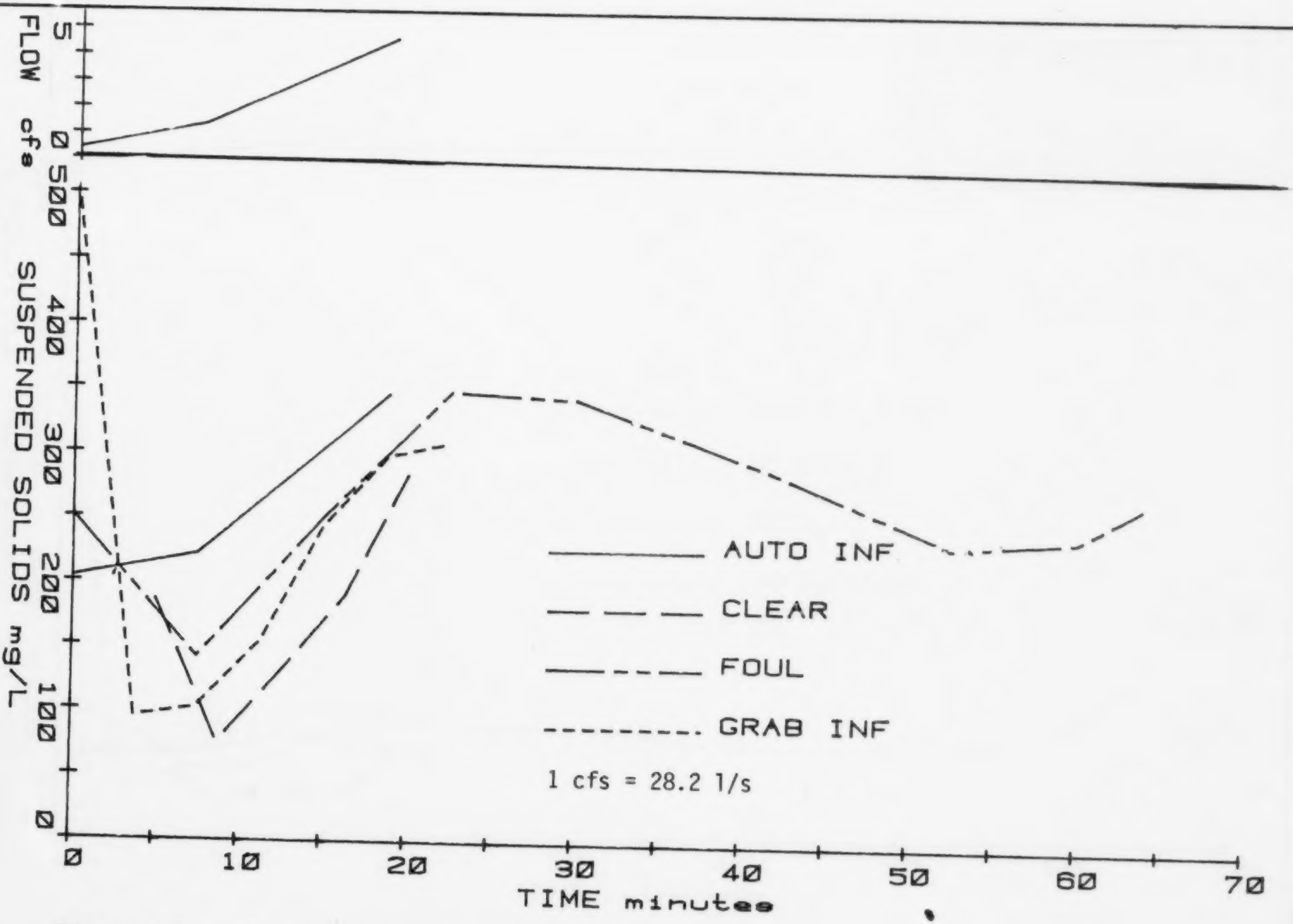


Figure 118. Suspended solids concentrations vs time, W. Roxbury Swirl Concentrator/Regulator (7/29/80).

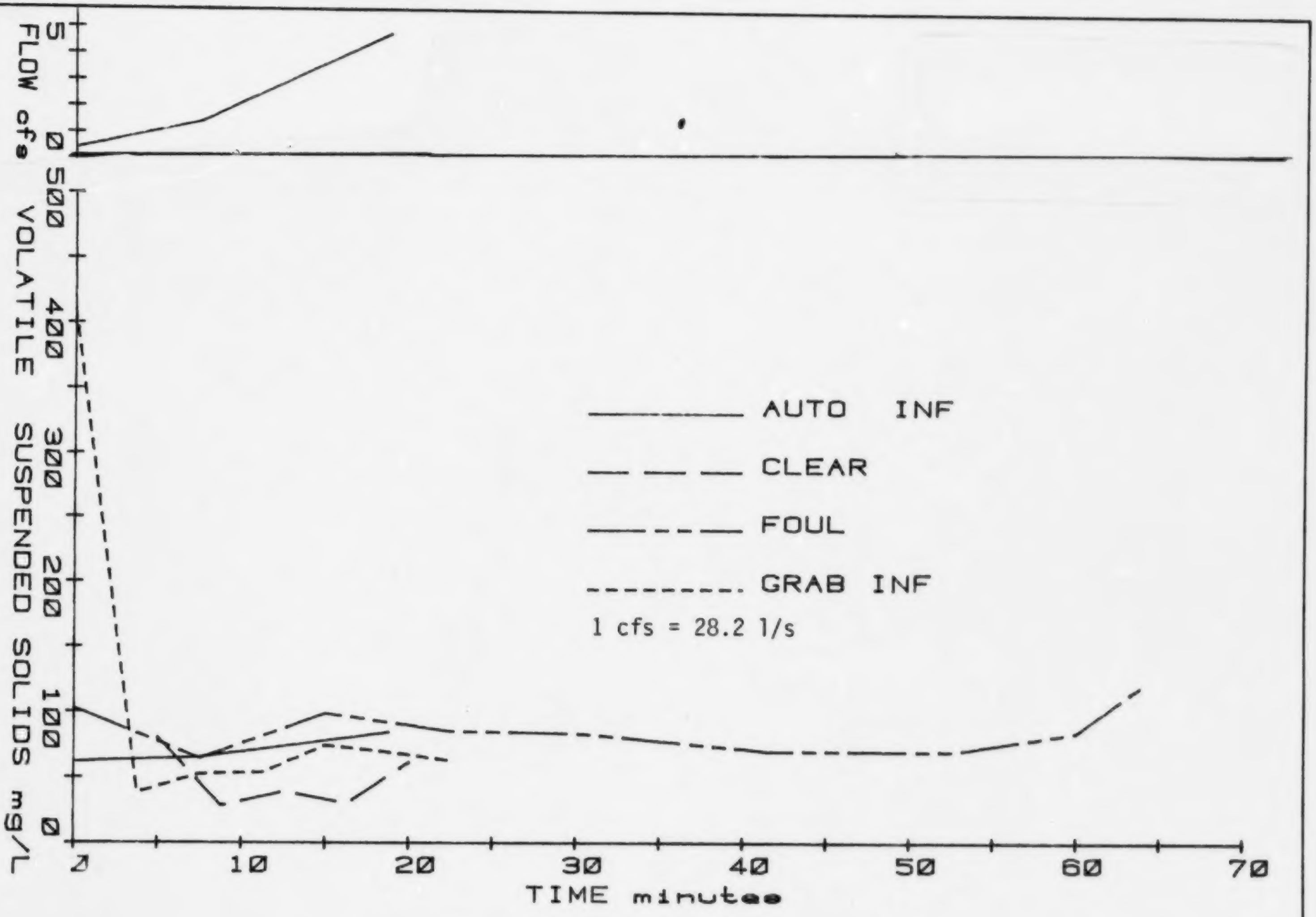


Figure 119. Volatile suspended solids concentrations vs time, W. Roxbury Swirl Concentrator/Regulator (7/29/80).

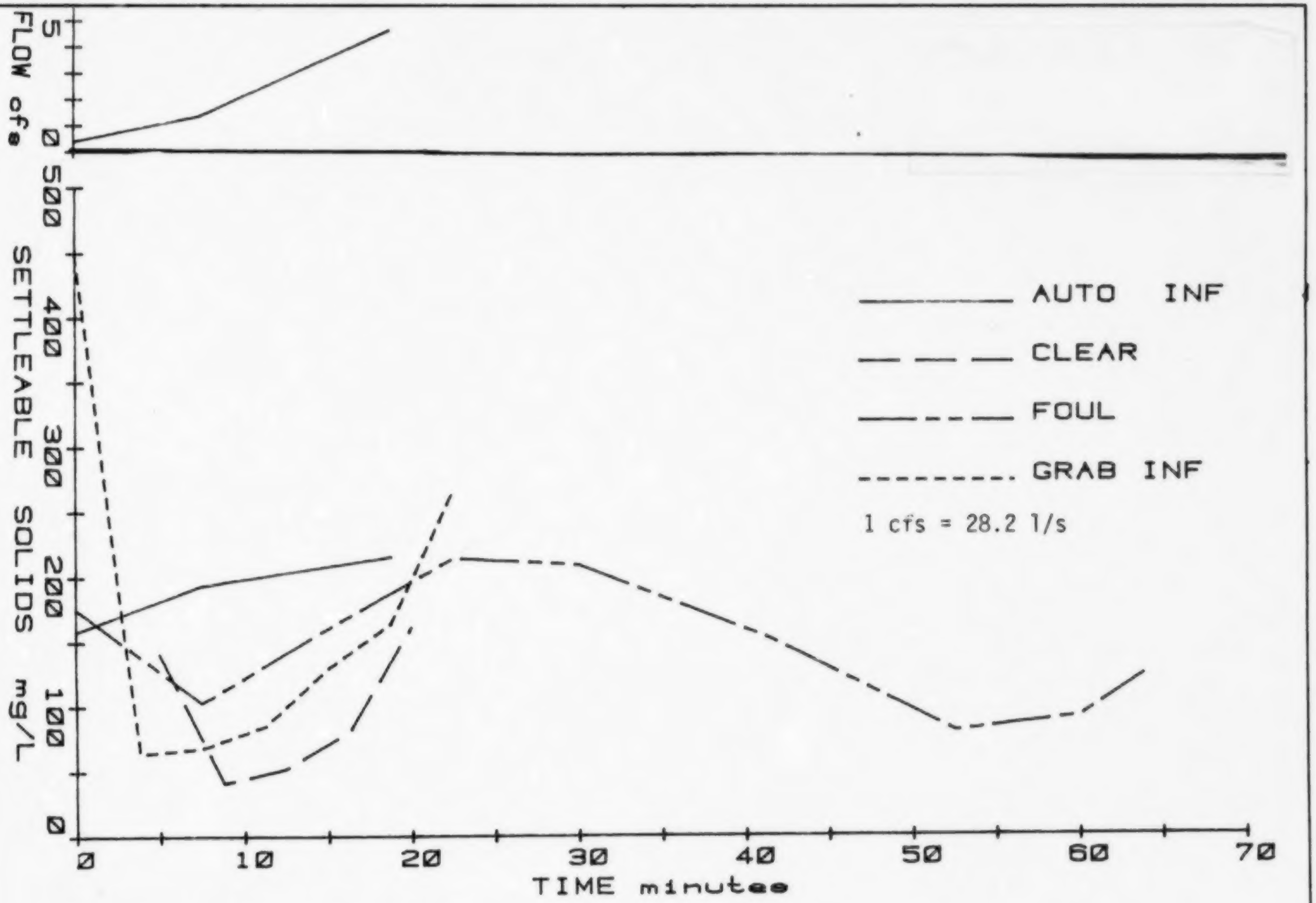
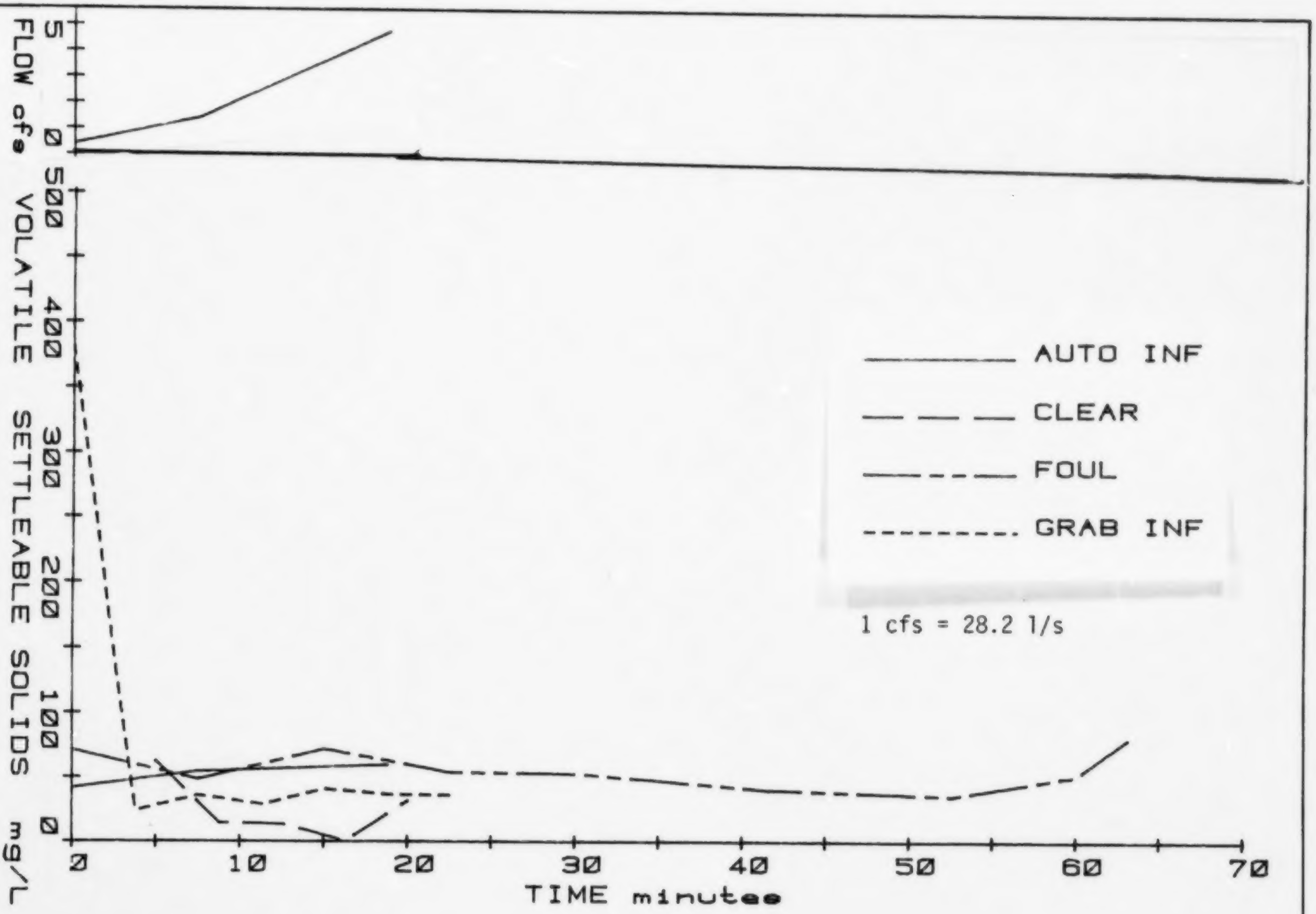


Figure 120. Settleable solids concentrations vs time, W. Roxbury Swirl Concentrator/Regulator (7/29/80).



1 cfs = 28.2 l/s

Figure 121. Volatile suspended solids concentrations vs time, W. Roxbury Swirl Concentrator/Regulator (7/29/80).

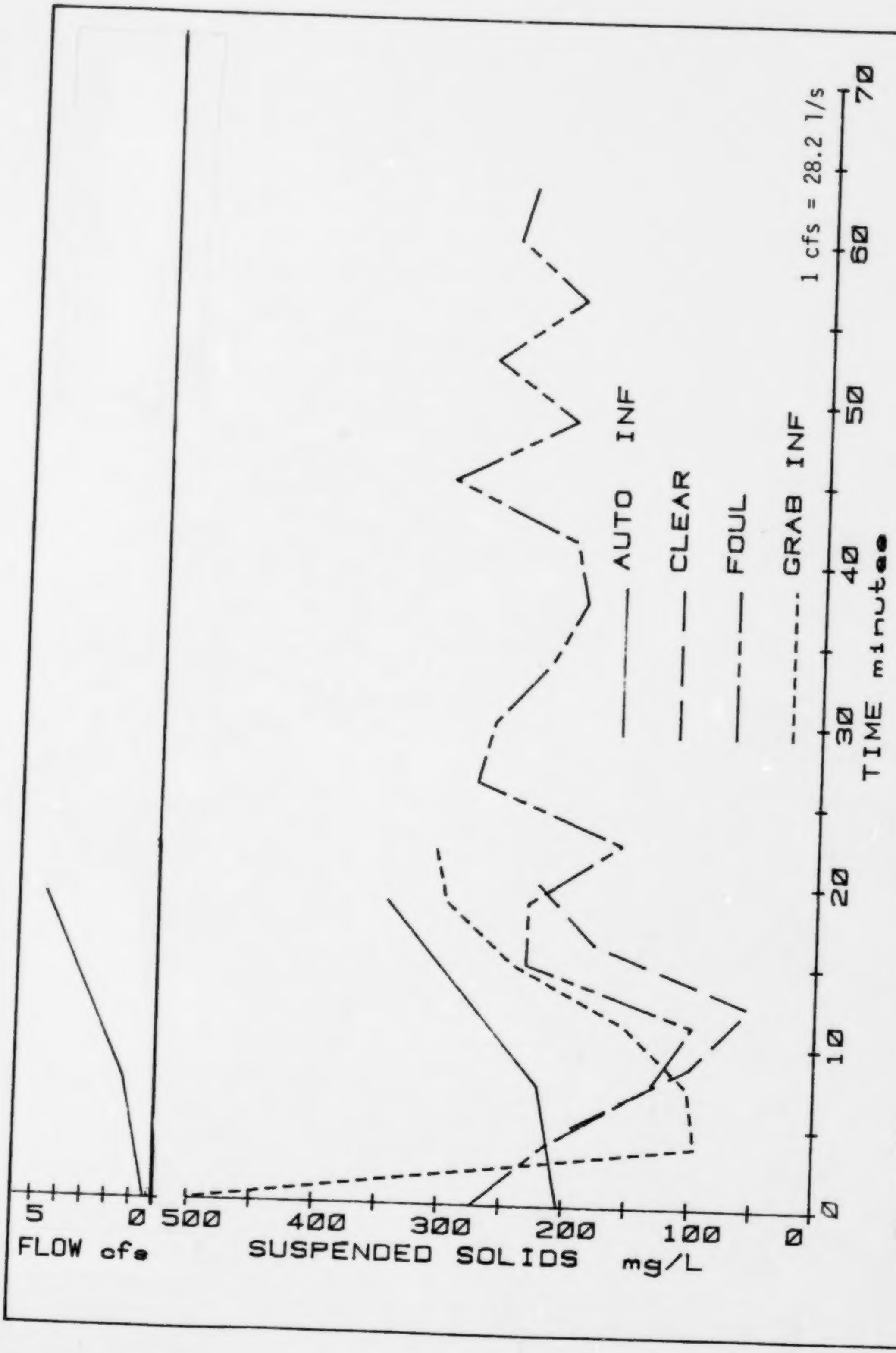


Figure 122. Suspended solids concentrations vs time, W. Roxbury Helical Bend Regulator (7/29/80).

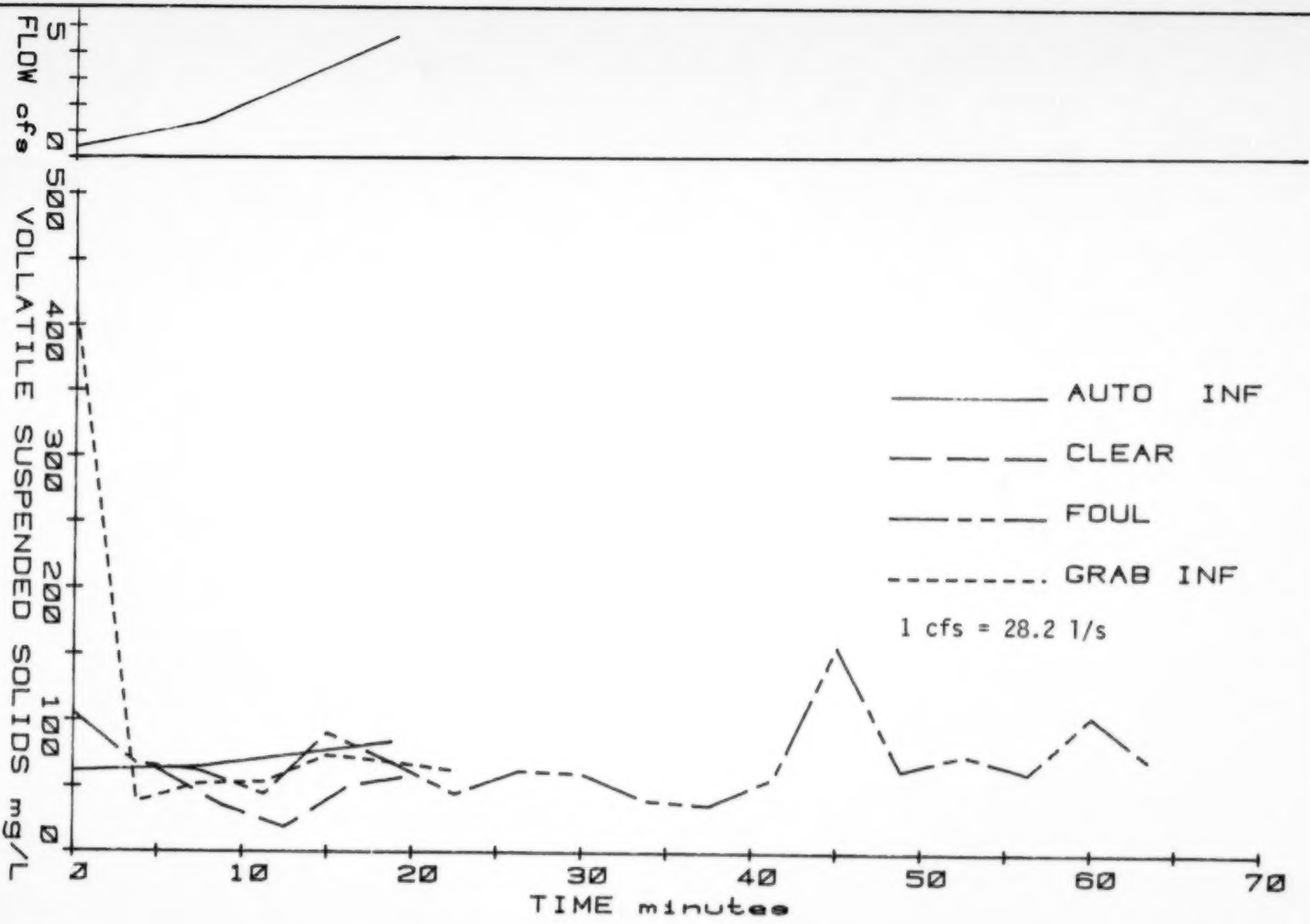


Figure 123. Volatile suspended solids concentrations vs time, W. Roxbury Helical Bend Regulator (7/29/80).

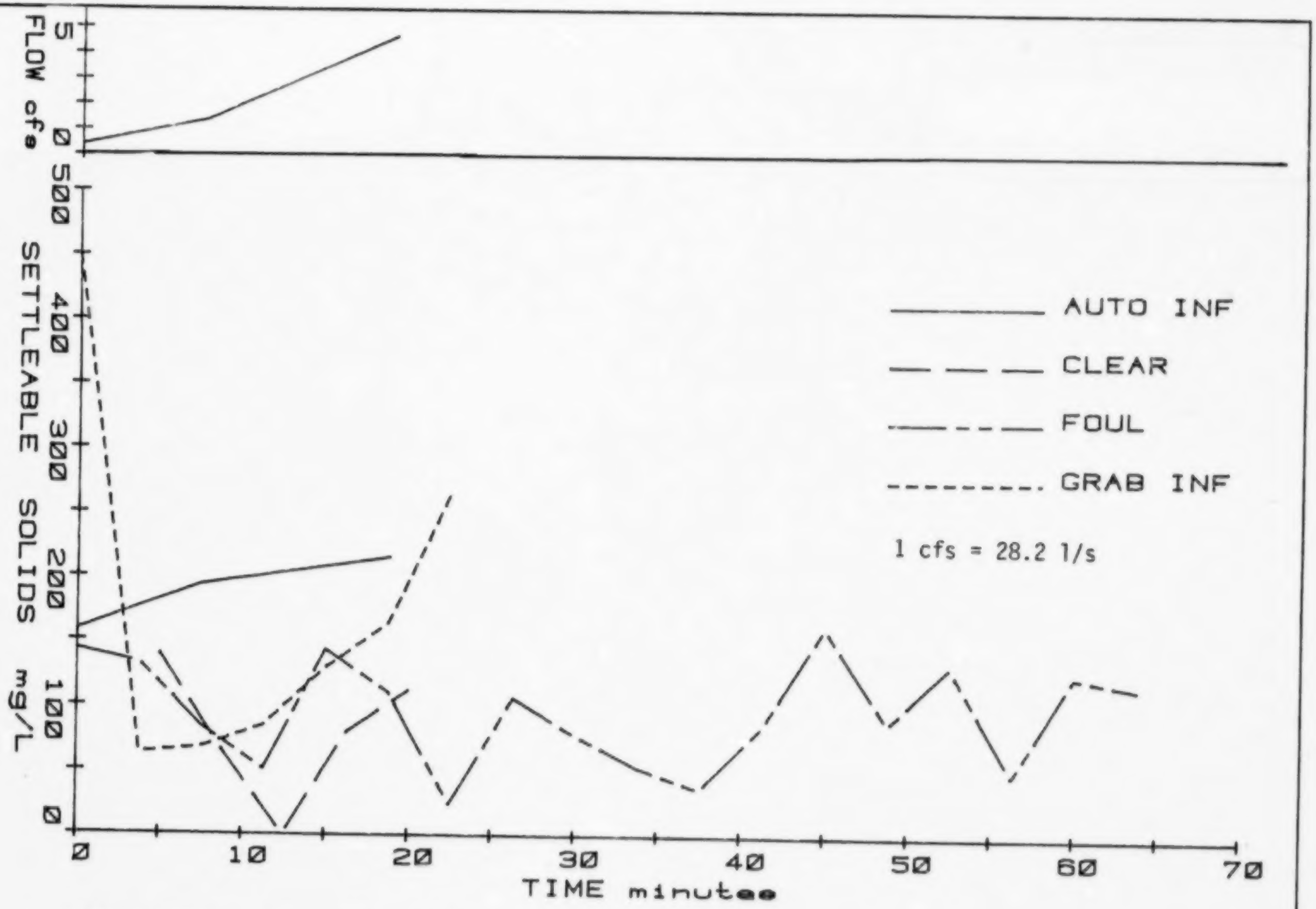


Figure 124. Settleable solids concentrations vs time, W. Roxbury Helical Bend Regulator (7/29/80)

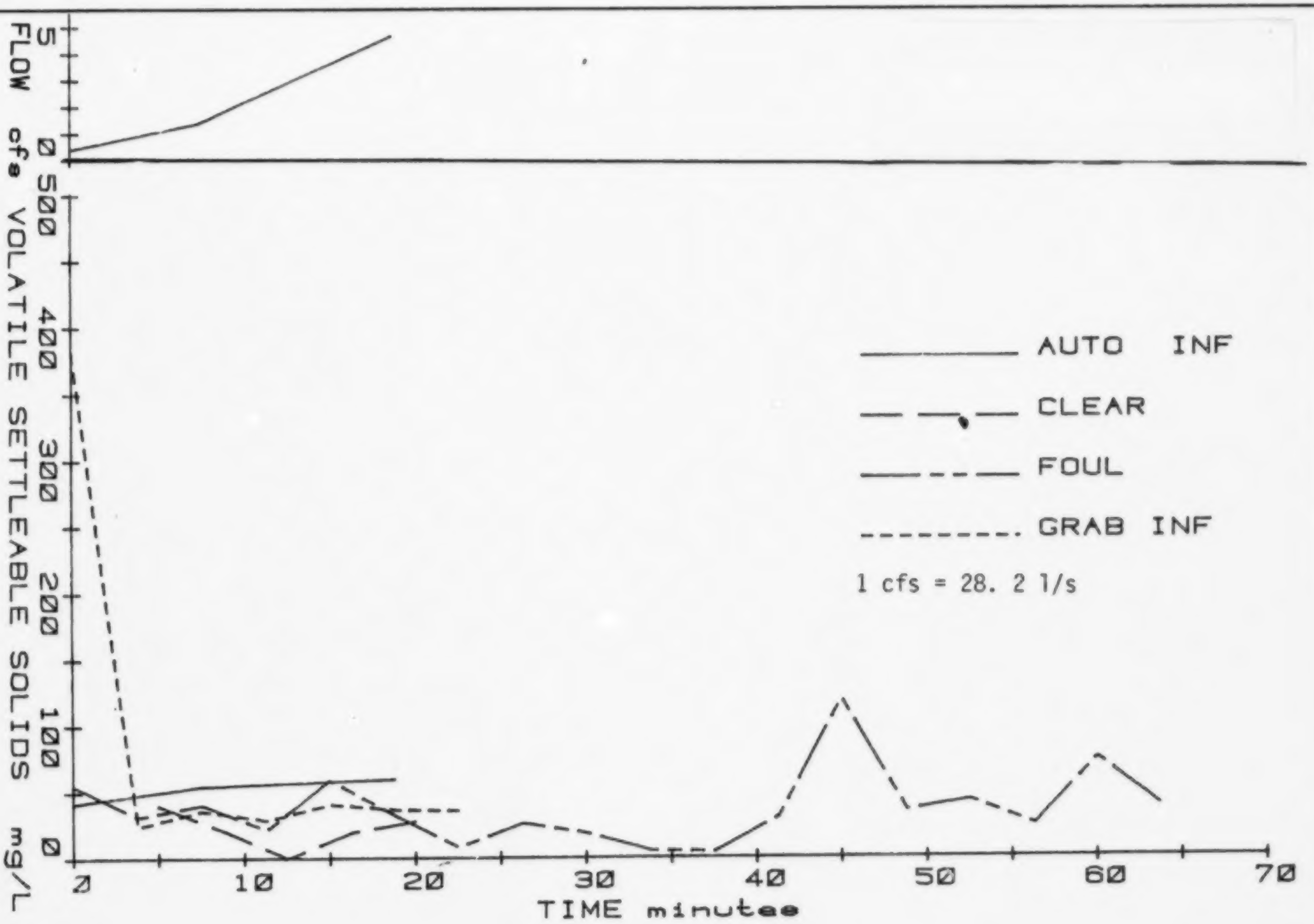


Figure 125. Volatile settleable solids concentrations vs time, W. Roxbury Helical Bend Regulator (7/29/80).

solids, settleable solids and volatile settleable solids are presented in Figures 126-129 respectively for the Swirl Concentrator and in Figures 130-133 respectively for the Helical Bend Regulator.

During the first 20 minutes of this event the flow into the Swirl increased from zero to 5 cfs (142 l/s) while the influent suspended concentrations decreased from 300 to 180 mg/l. The removal rate averaged 22% over the first ten minutes, followed by 10 minutes of higher clear overflow solids concentrations. Between the 20 and the 40 minute point of this event the flow remained constant at 6 cfs (170 l/s) and influent solids concentration rose to 850 mg/l with average removal and efficiency rates of 36% and 32% . During the final 10 minutes of operation influent concentrations fell sharply to 150 mg/l and the removal rate fell to 5% while averaging 8% at an efficiency of 7.2%.

The Swirl foul flow concentration factor averaged 1.056 between 10 and 50 minutes indicating a removal rate of 7% and an efficiency of 6.5% . These values are lower than estimated by clear flow considerations implying tank concentration solids buildup or deposition on the tank floor. Foul flow solids concentrations rose sharply during final drawdown clearly indicating the presence of this material.

The Helical Bend demonstrated no removals during this event based on relative influent and clear sample concentrations. After 5 minutes of operation the unit demonstrated reasonable removal based on foul sample analysis. The foul flow concentration factor averaged 1.375 during this period at an average flow of 4.5 cfs (127 l/s). Removal rate and efficiency averages were 16% and 10% respectively. In addition, the final drawdown samples contained increased solids concentration indicating additional removal.

## 10/25/80 Results Summary

Plots of time vs influent, clear and foul sewer pollutant concentrations of suspended solids, volatile suspended solids, settleable solids and volatile settleable solids are presented in Figures 134-137 respectively for the Swirl Concentrator and in Figures 138-141 respectively for the Helical Bend Regulator.

On the basis of clear sample concentrations the Swirl unit provided no removal, as clear overflow solids concentrations were typically higher than inflow values. Ratios of foul to influent solids concentration ranged from 1.07 to

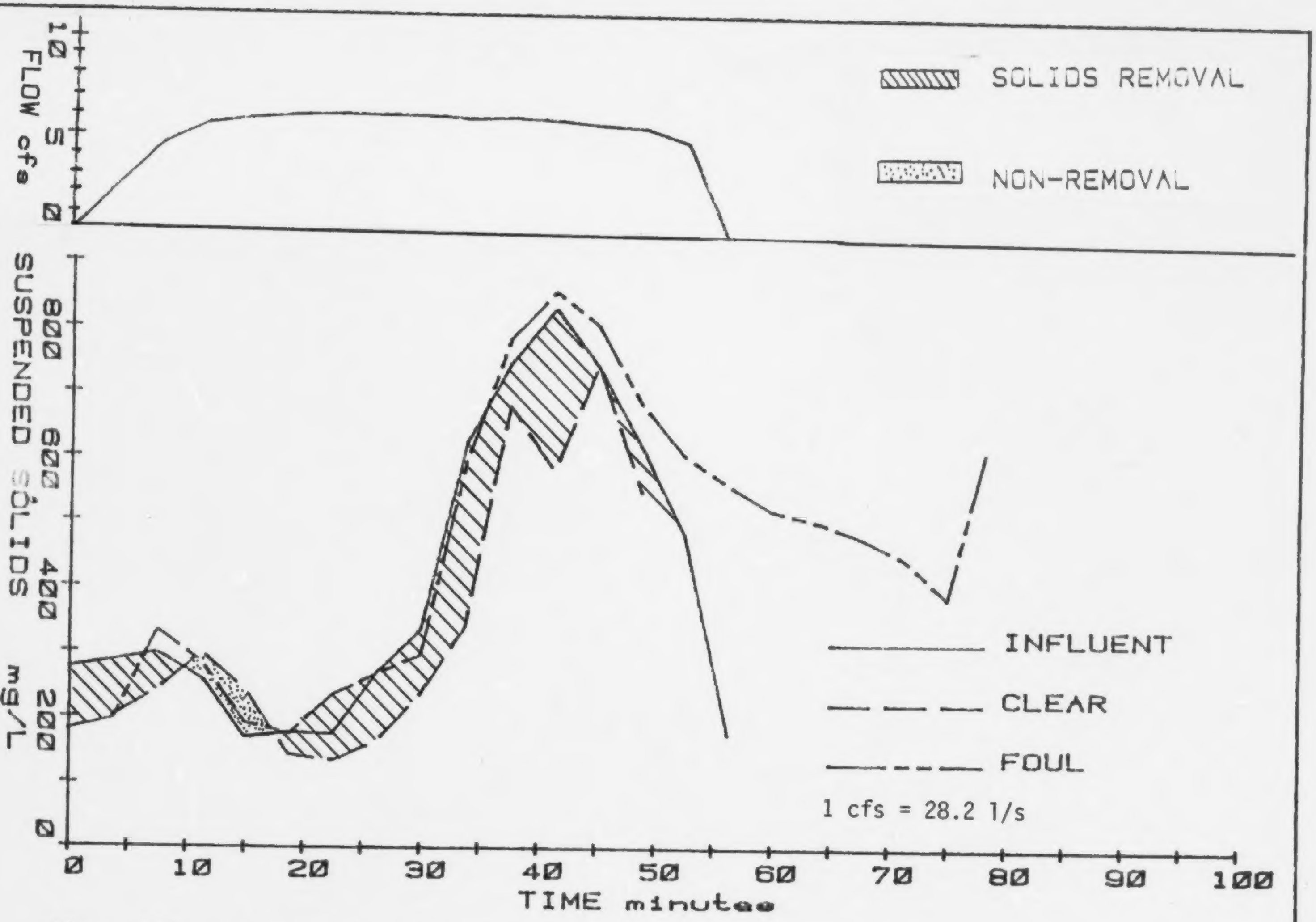


Figure 126. Suspended solids concentrations vs time, W. Roxbury Swirl Concentrator/Regulator (10/3/80).

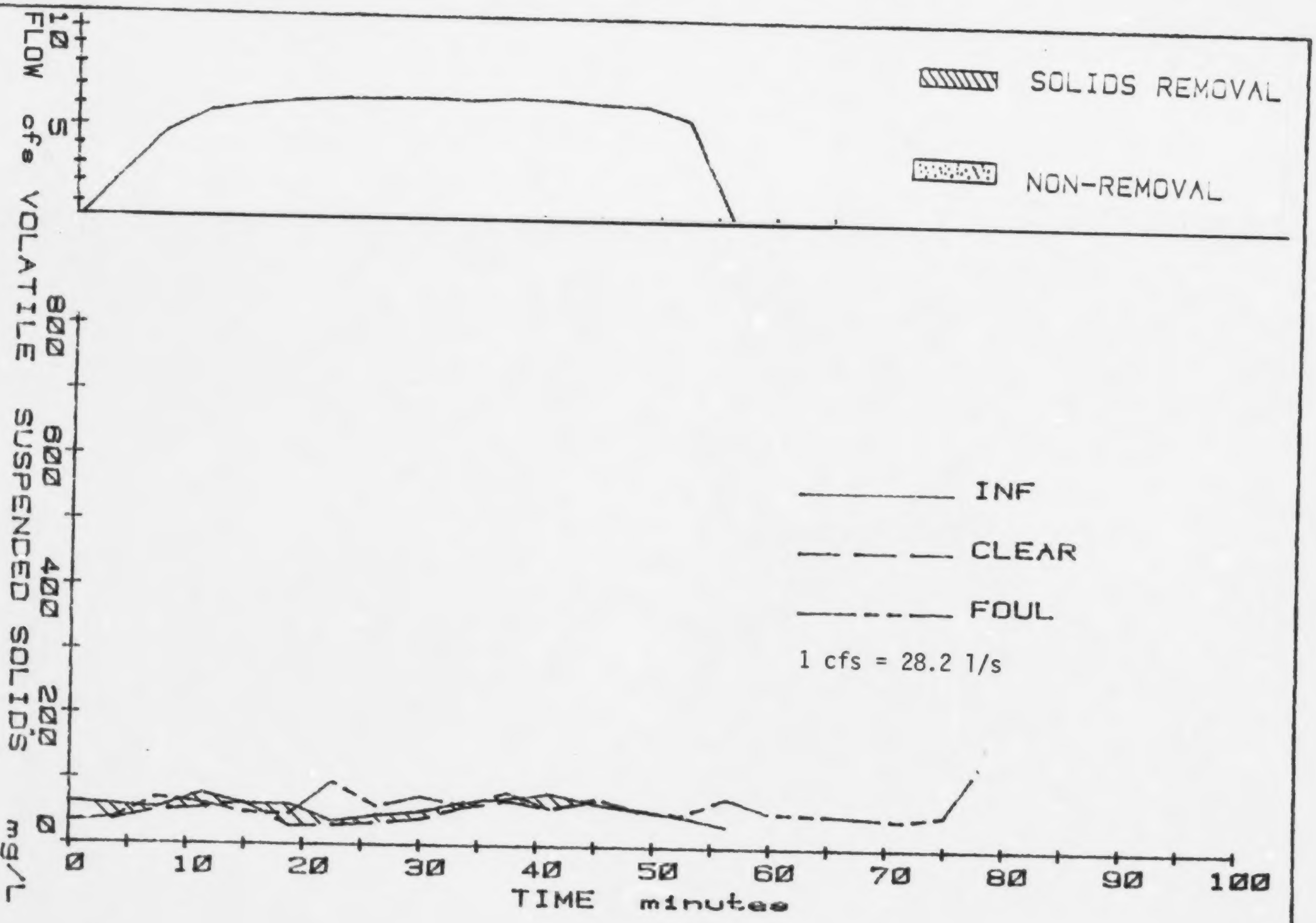


Figure 127. Volatile suspended solids concentrations vs time, W. Roxbury Swirl Concentrator/Regulator (10/3/80).

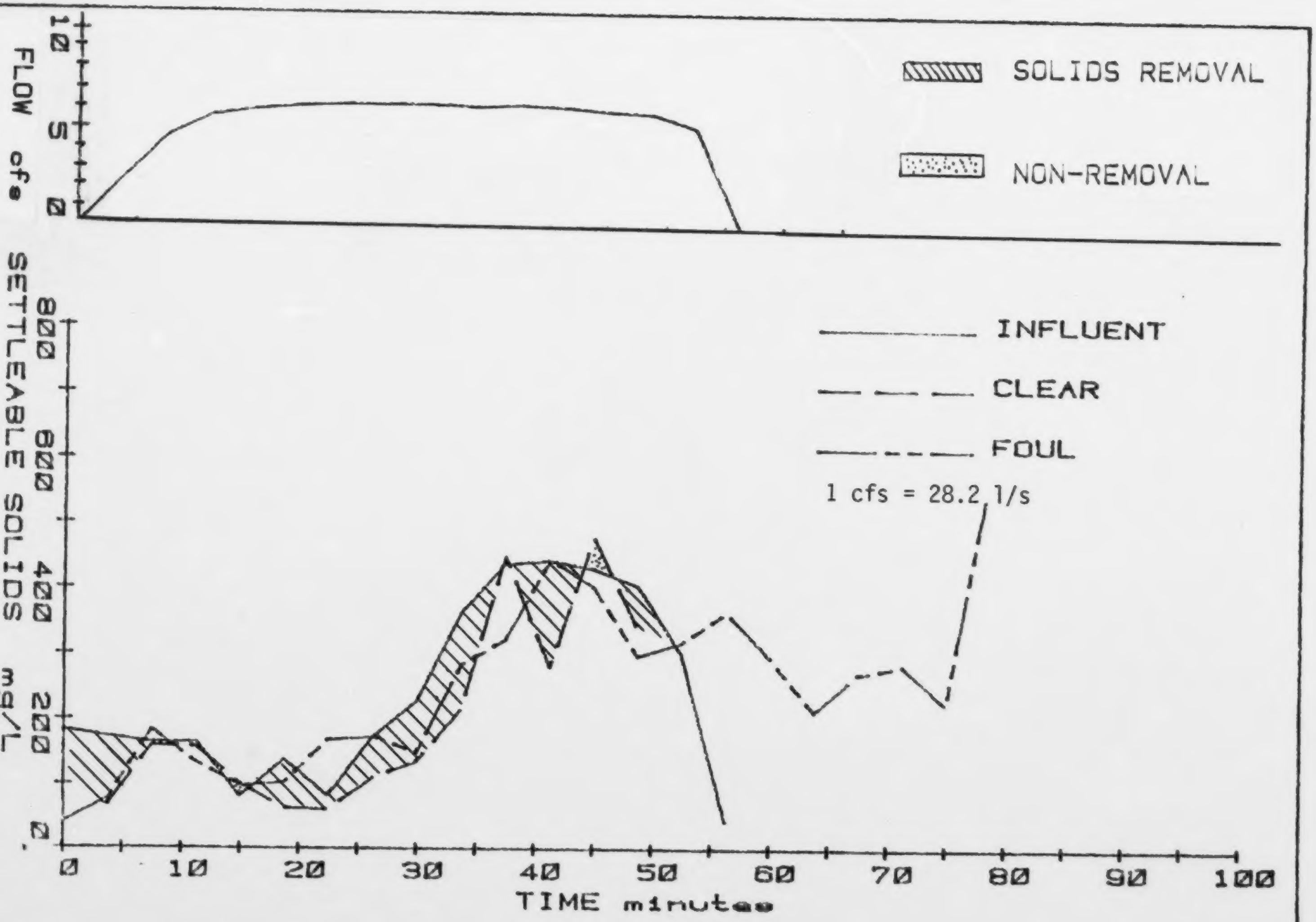


Figure 128. Settleable solids concentration vs time, W. Roxbury Swirl Concentrator/Regulator (10/3/80).

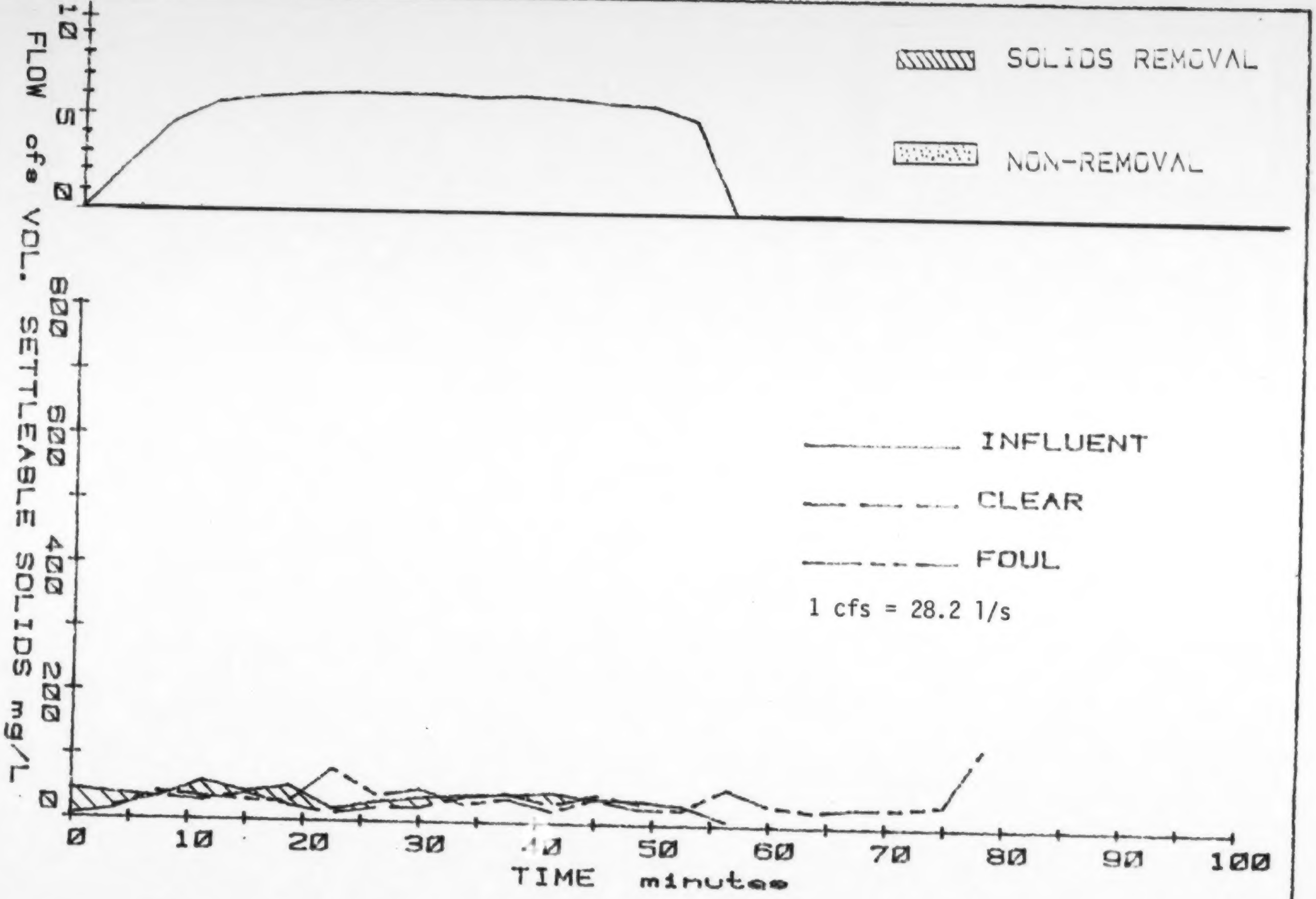


Figure 129. Volatile settleable solids concentrations vs time, W. Roxbury Swirl Concentrator/Regulator (10/3/80).

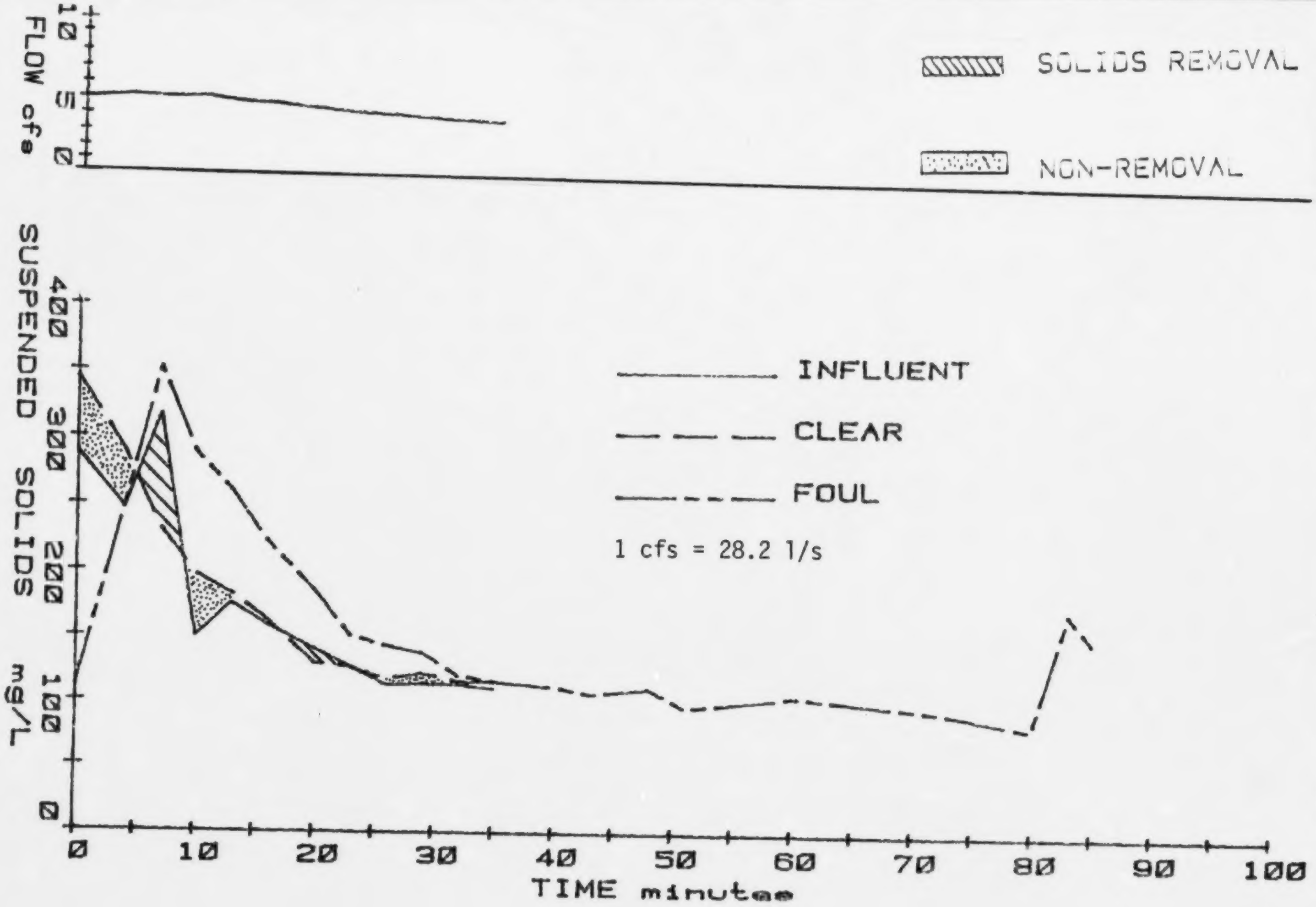


Figure 130. Suspended solids concentrations vs time, W. Roxbury Helical Bend Regulator (10/3/80).

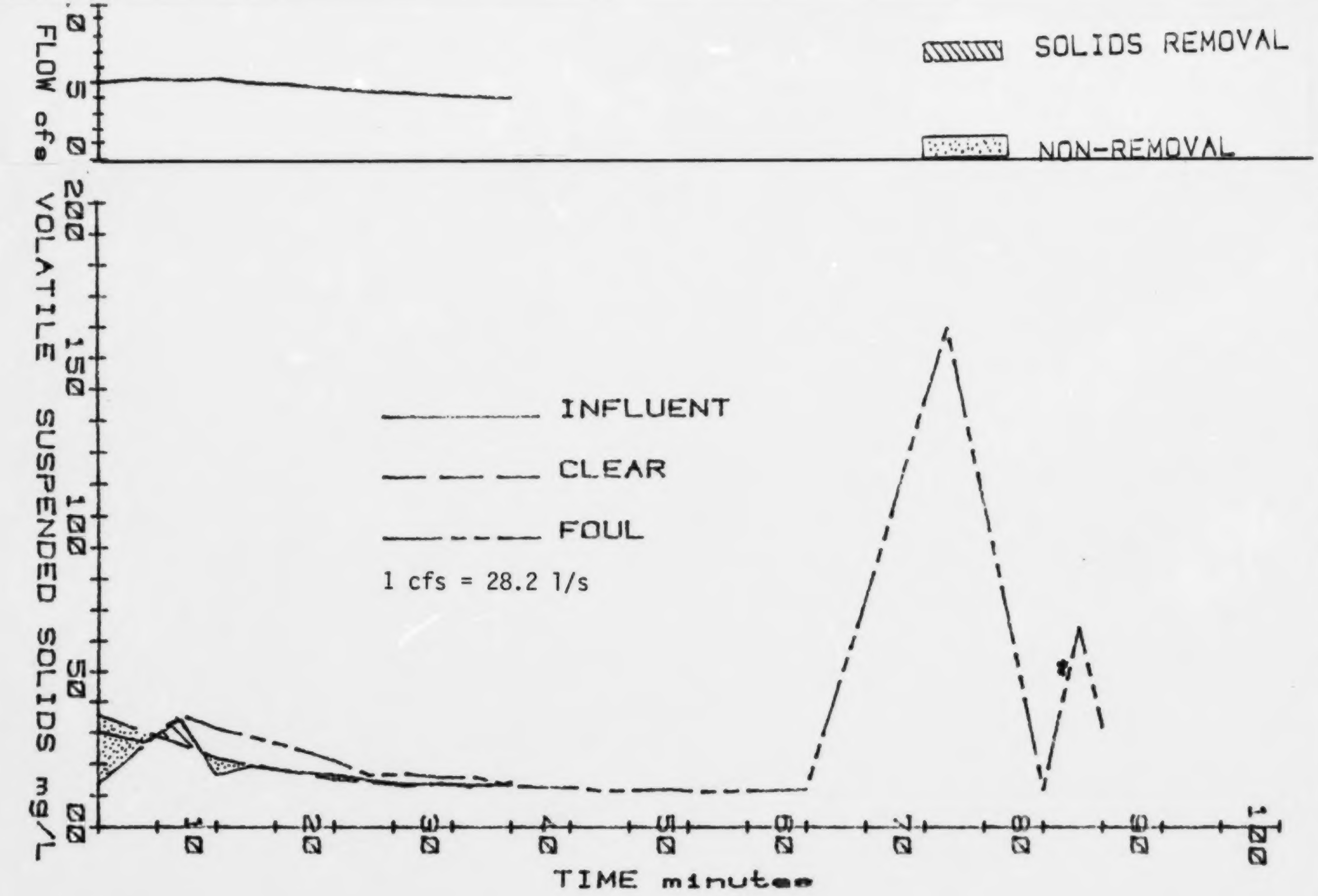


Figure 131. Volatile suspended solids concentrations vs time, W. Roxbury Helical Bend Regulator (10/3/80).

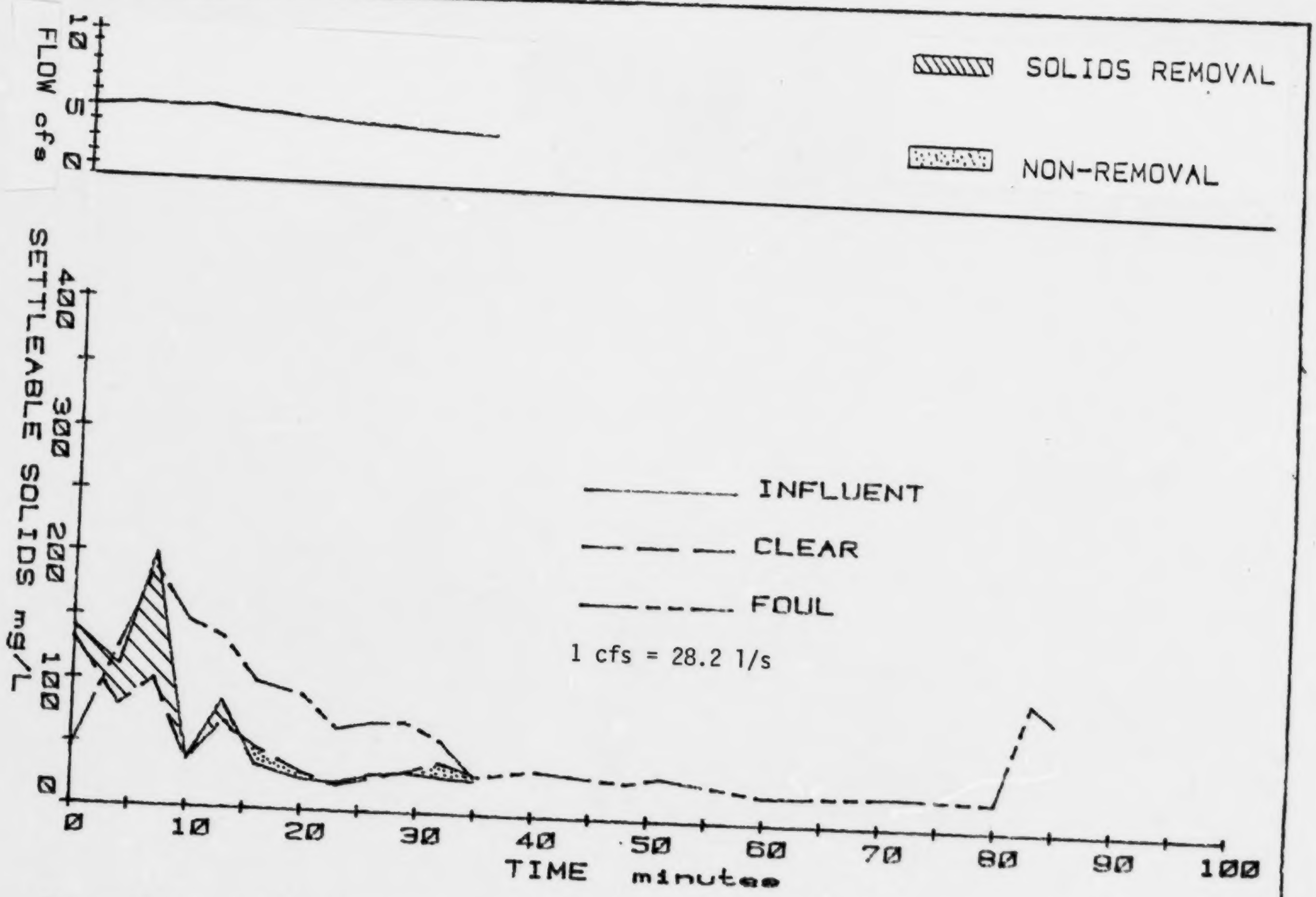


Figure 132. Settleable solids concentrations vs time, W. Roxbury Helical Bend Regulator (10/3/80).

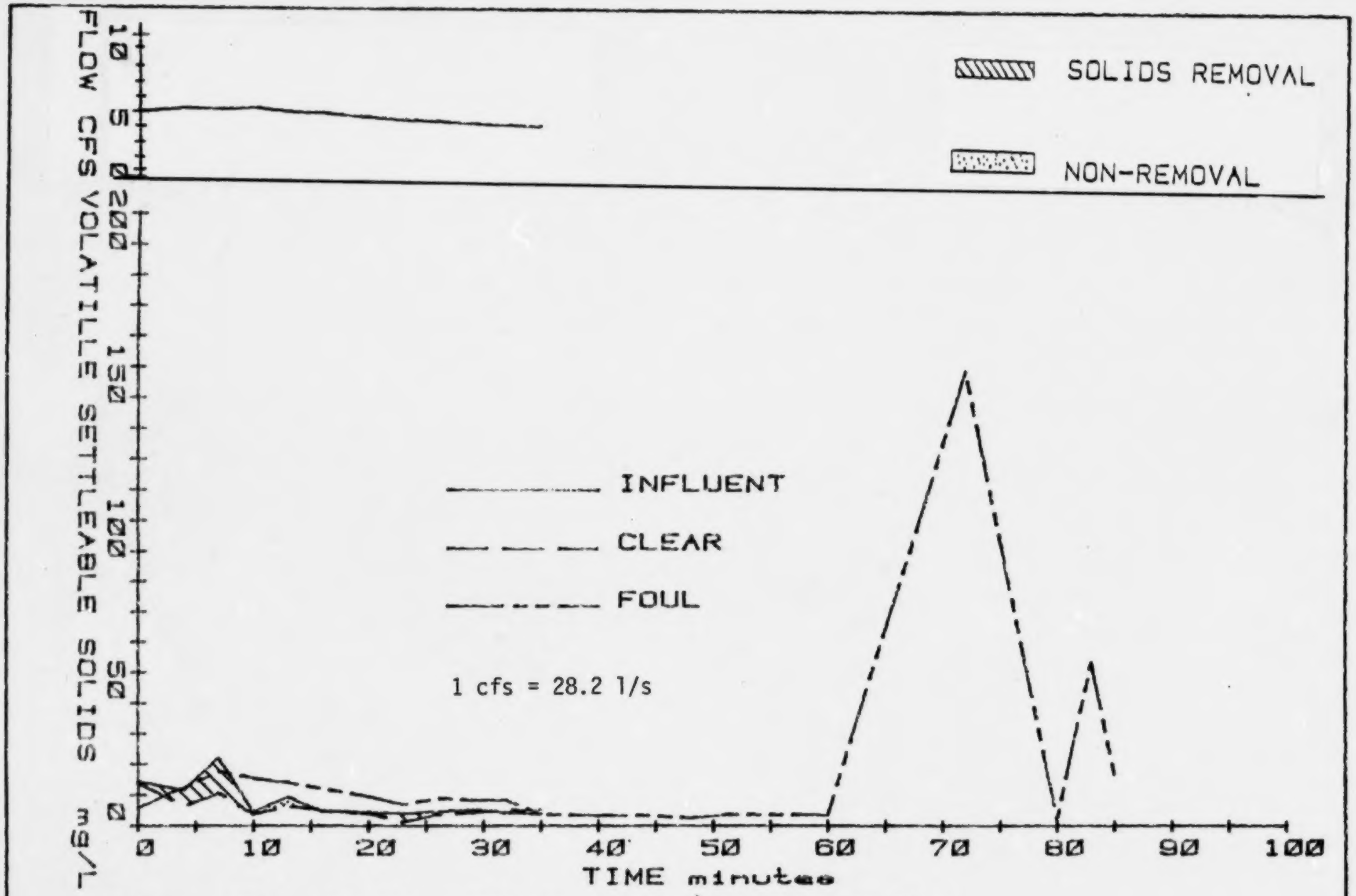


Figure 133. Volatile settleable solids concentrations vs time, W. Roxbury Helical Bend Regulator (10/3/80).

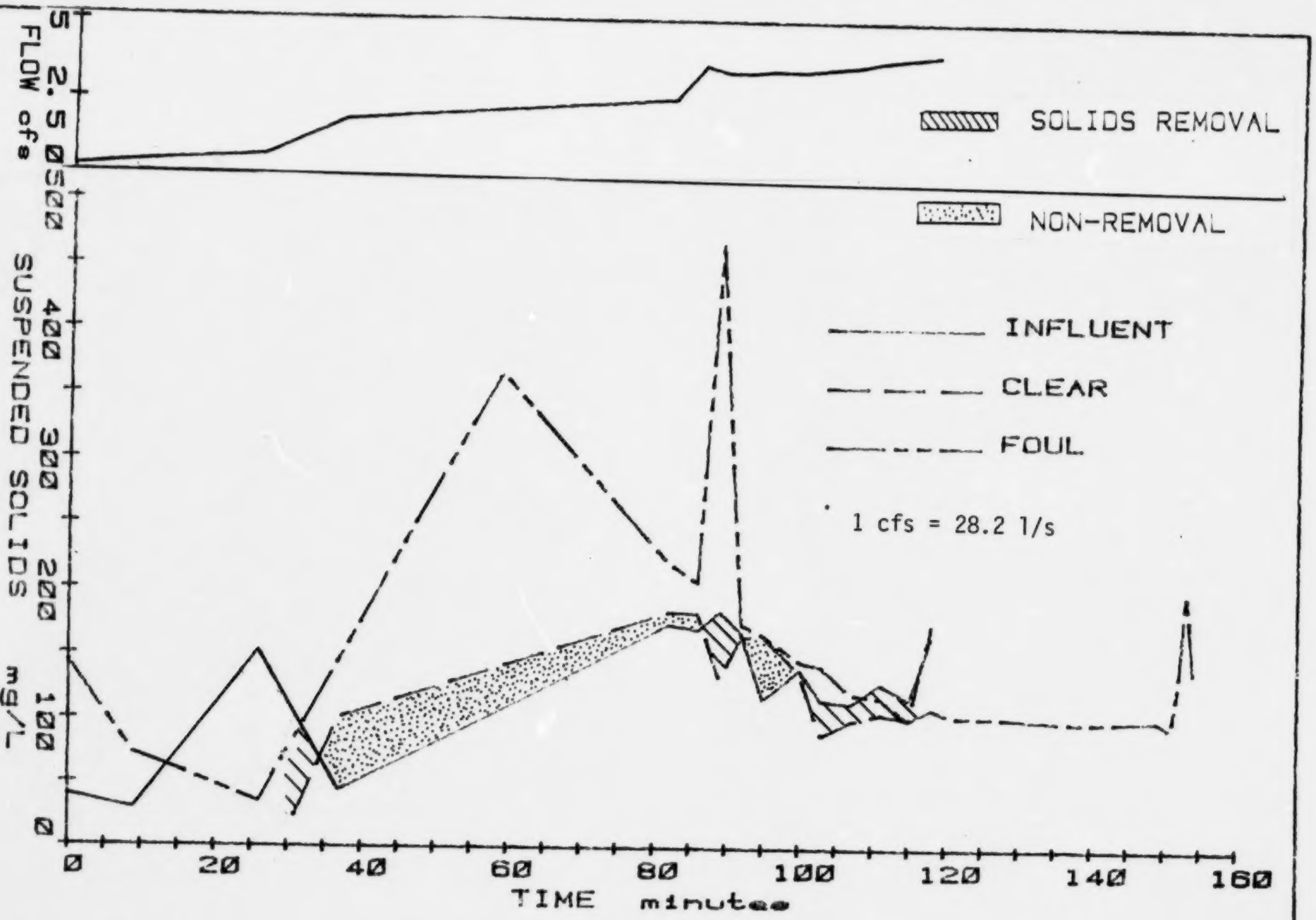


Figure 134. Suspended solids concentrations vs time, Swirl Concentrator/Regulator (10/25/80).

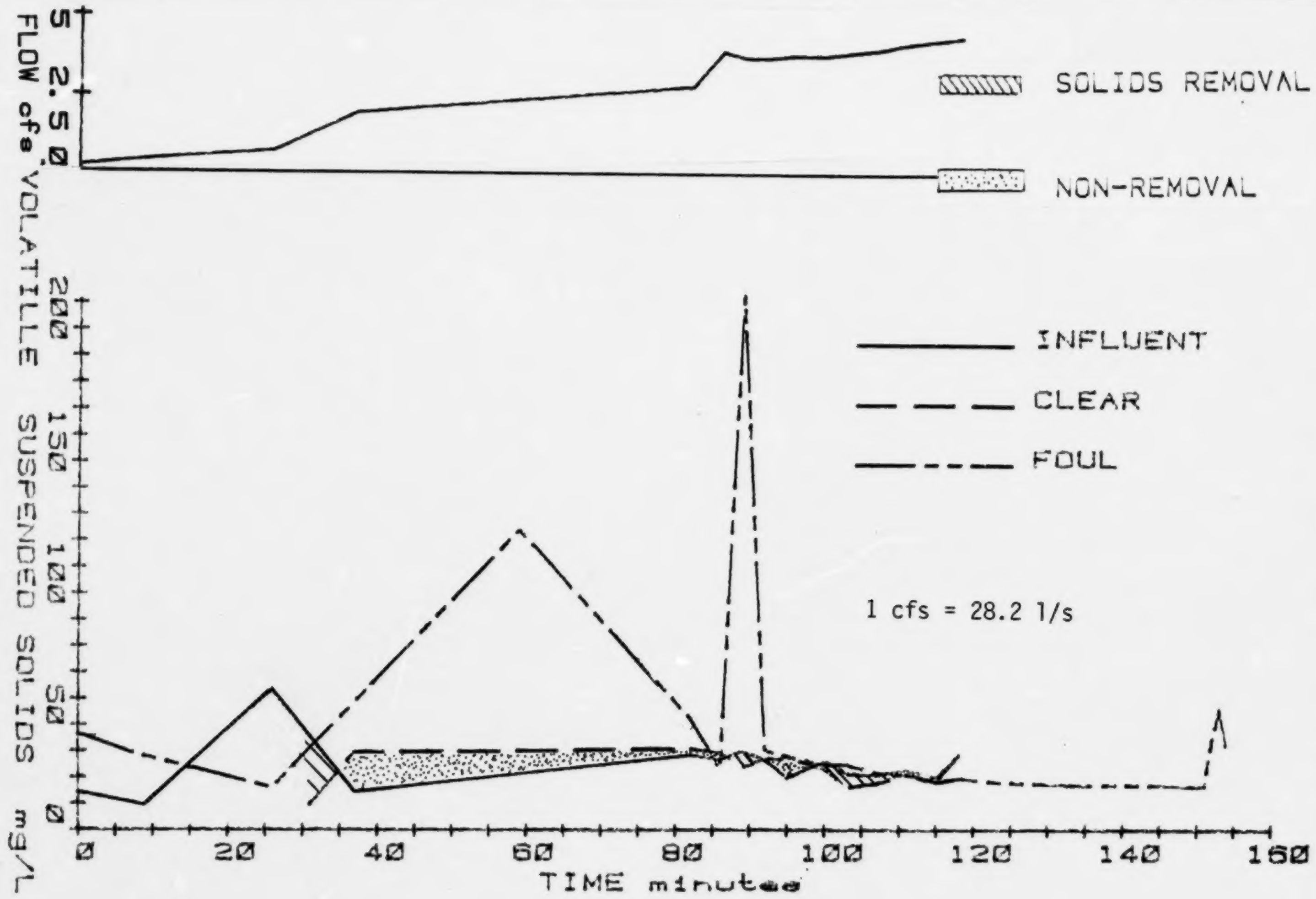


Figure 135. Volatile suspended solids concentrations vs time, W. Roxbury Swirl Concentrator/Regulator (10/25/80).

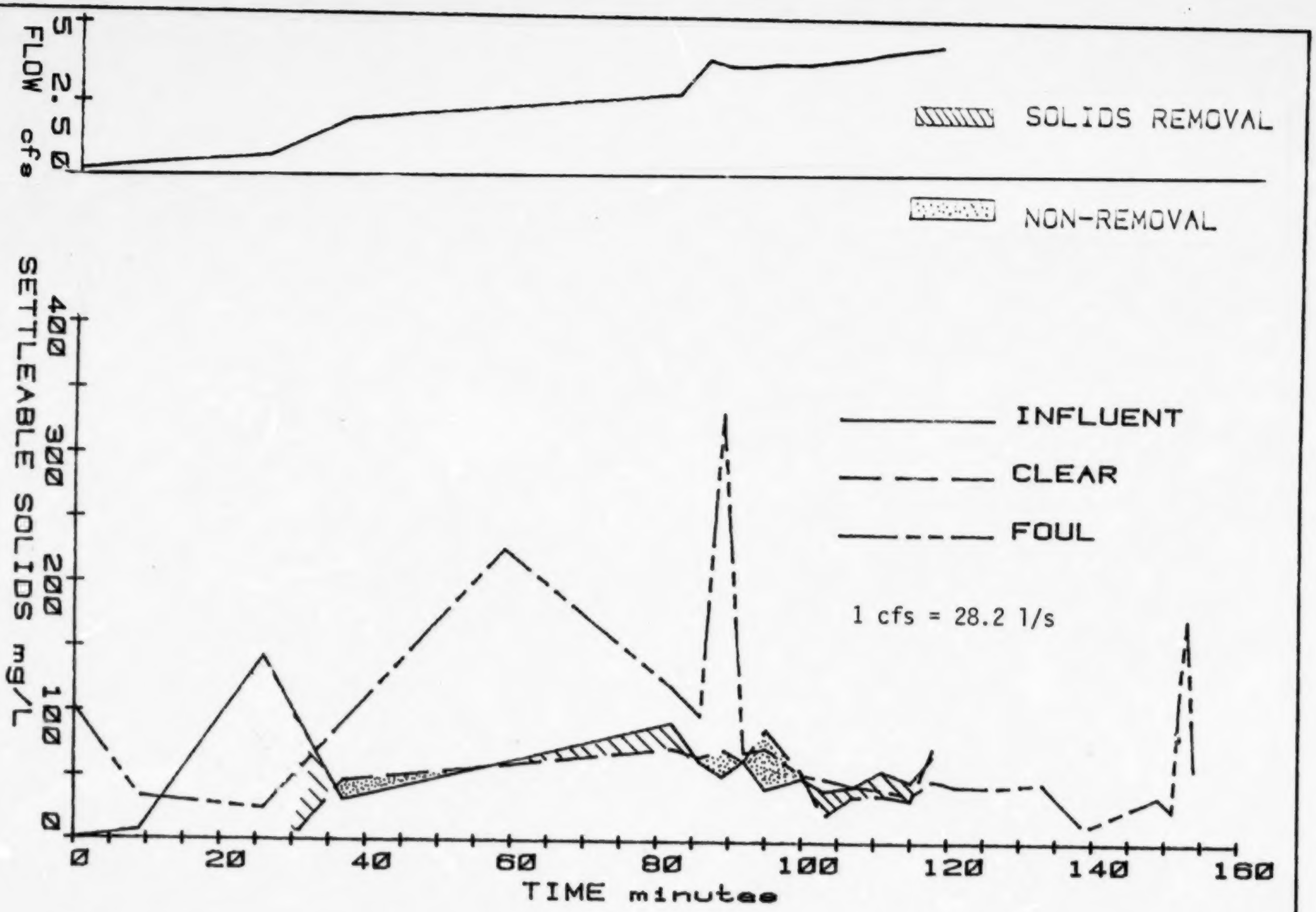


Figure 136. Settleable solids concentrations vs time, W. Roxbury Swirl Concentrator/Regulator (10/25/80).

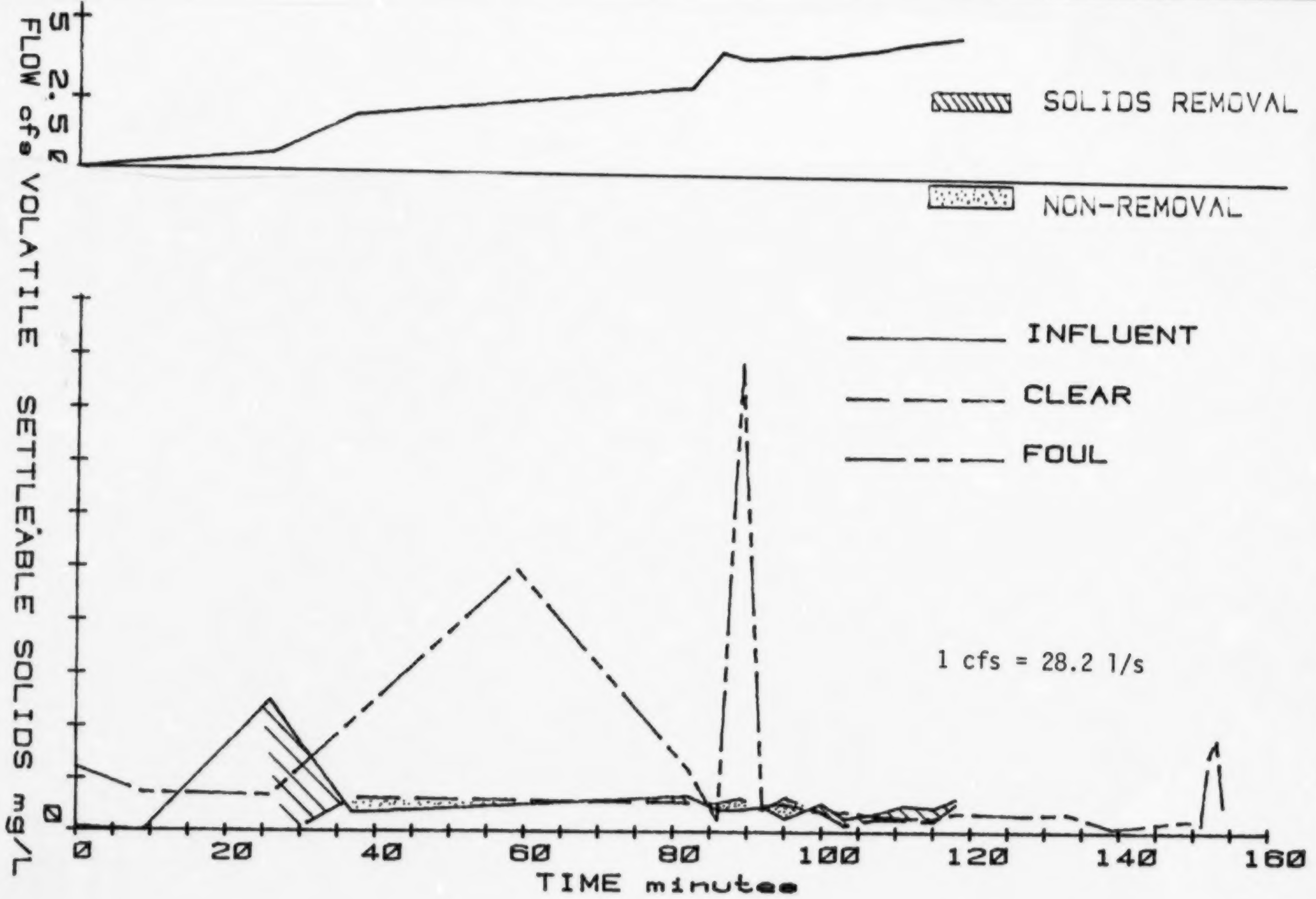


Figure 137. Volatile settleable solids concentrations vs time, W. Roxbury Swirl Concentrator/Regulator (10/25/80).

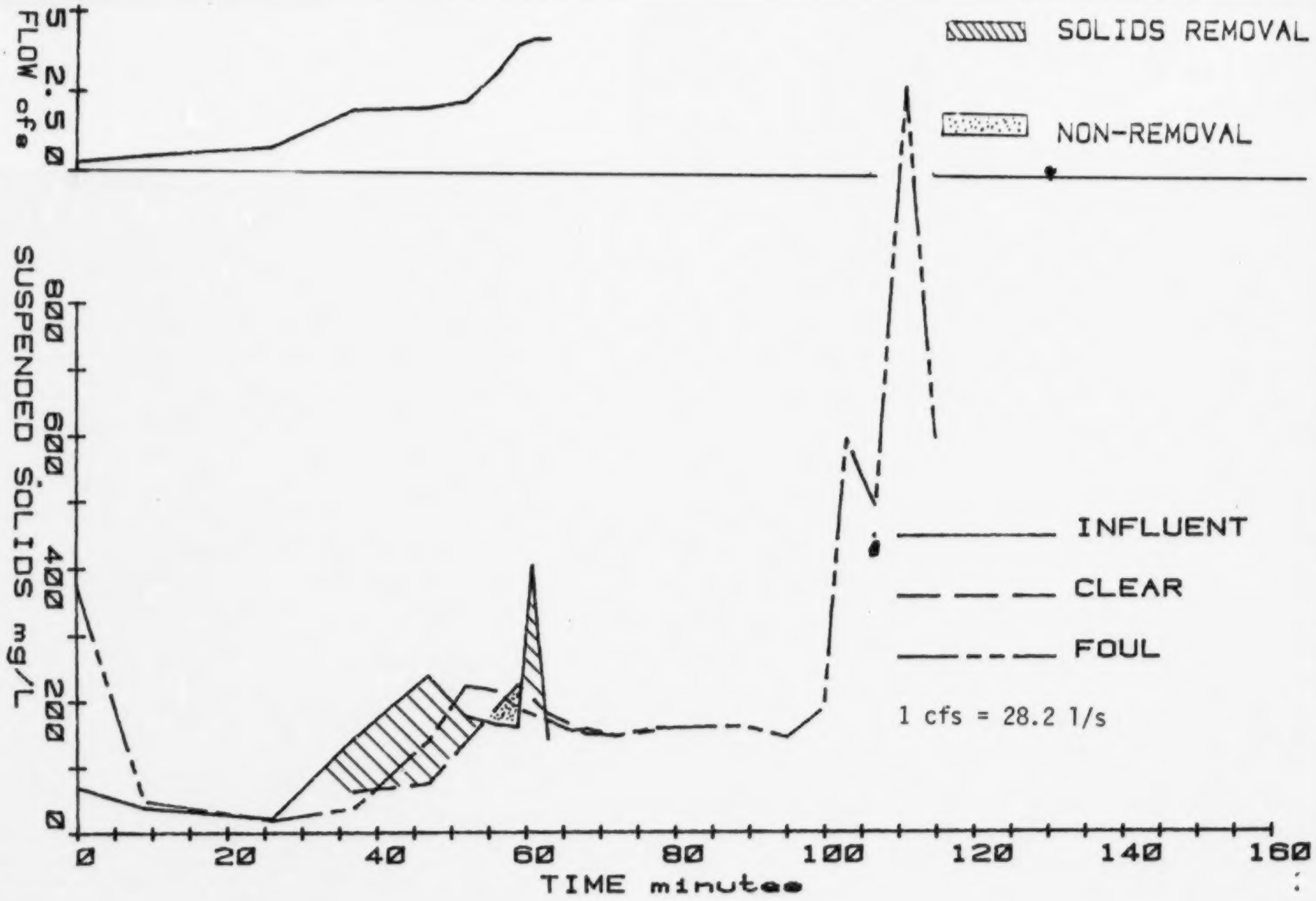


Figure 138. Suspended solids concentrations vs time, W. Roxbury Helical Bend Regulator (10/25/80).

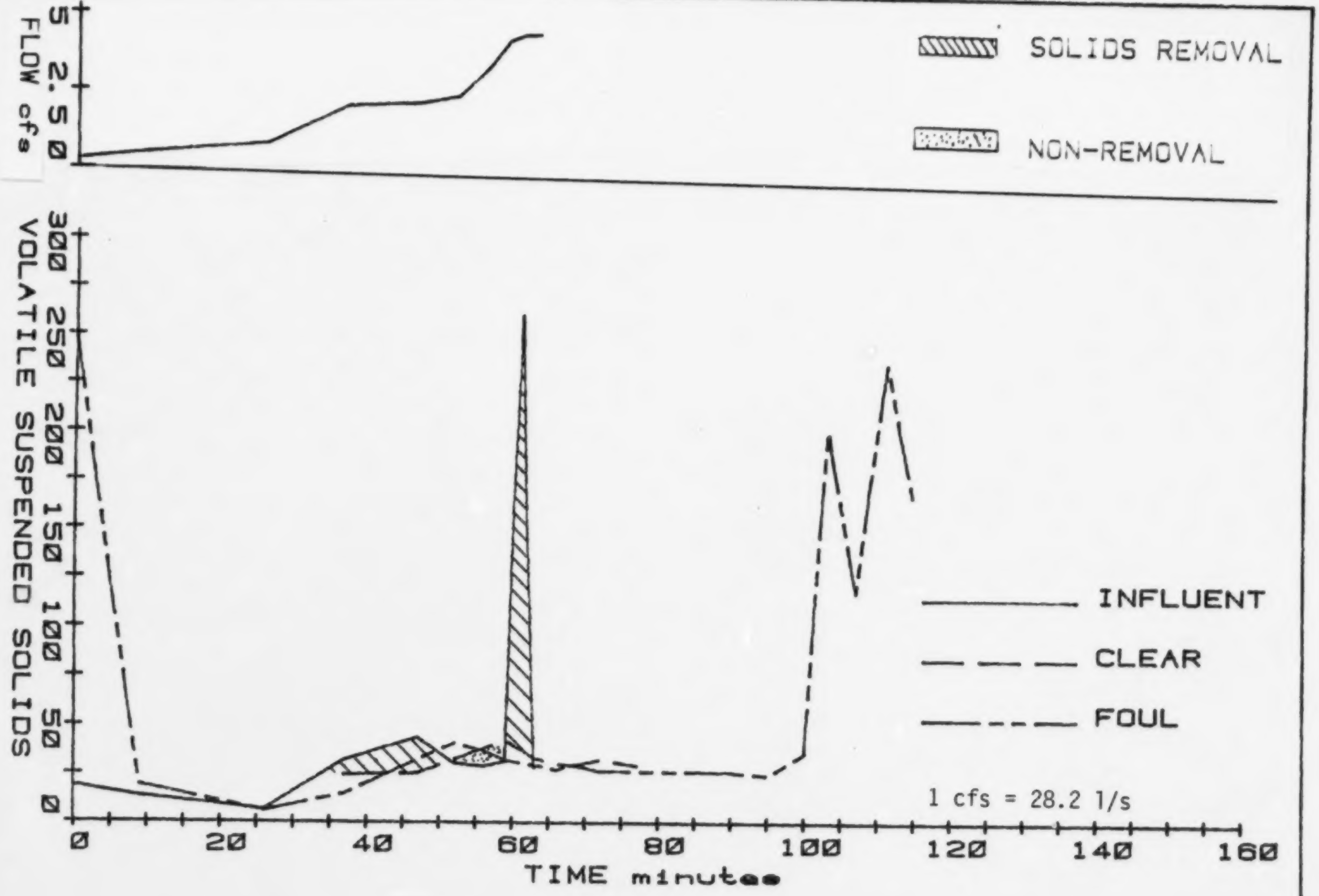


Figure 139. Volatile suspended solids concentrations vs time, W. Roxbury Helical Bend Regulator (10/25/80).

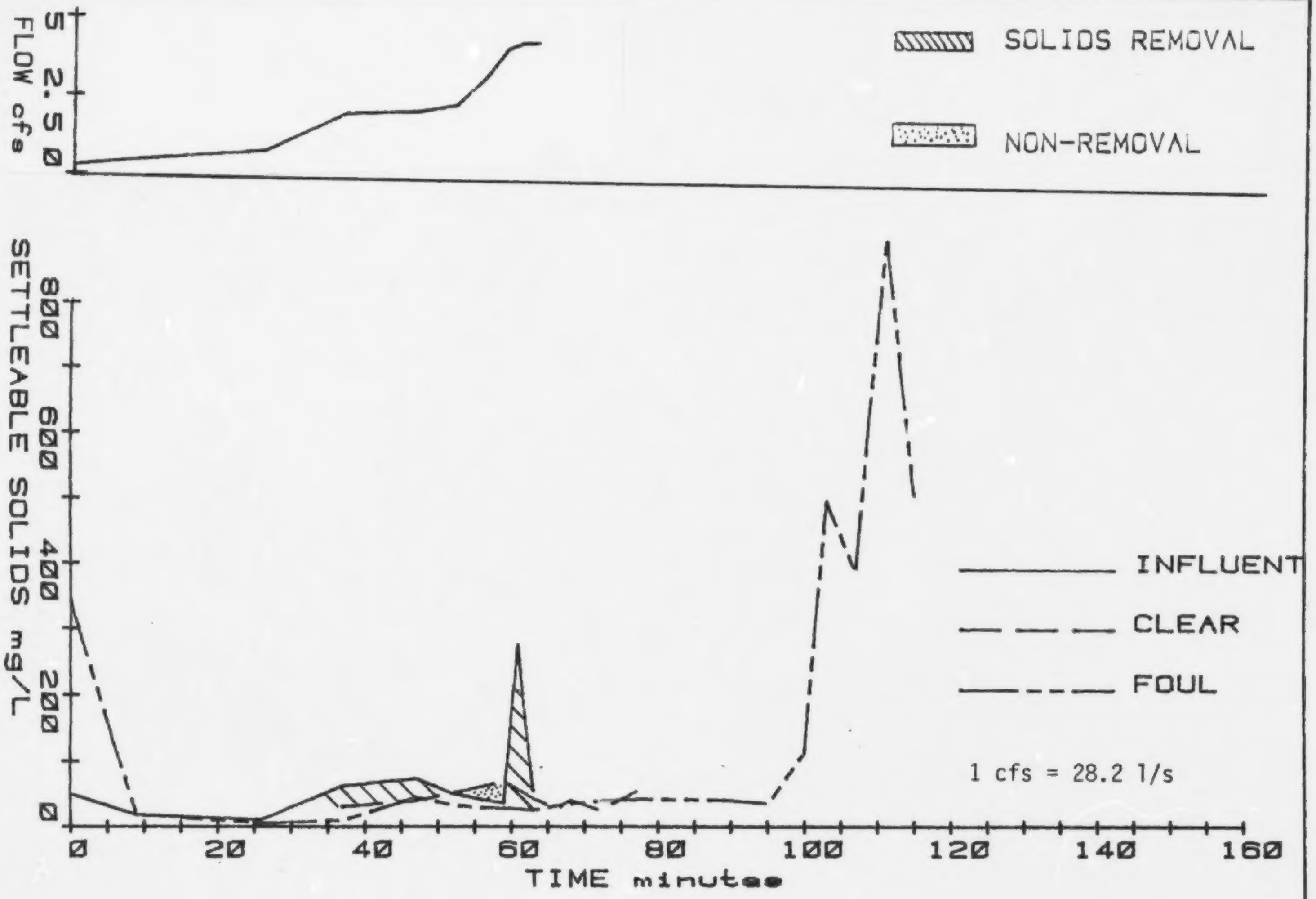


Figure 140. Settleable solids concentrations vs time, W. Roxbury Helical Bend Regulator, (10/25/80).

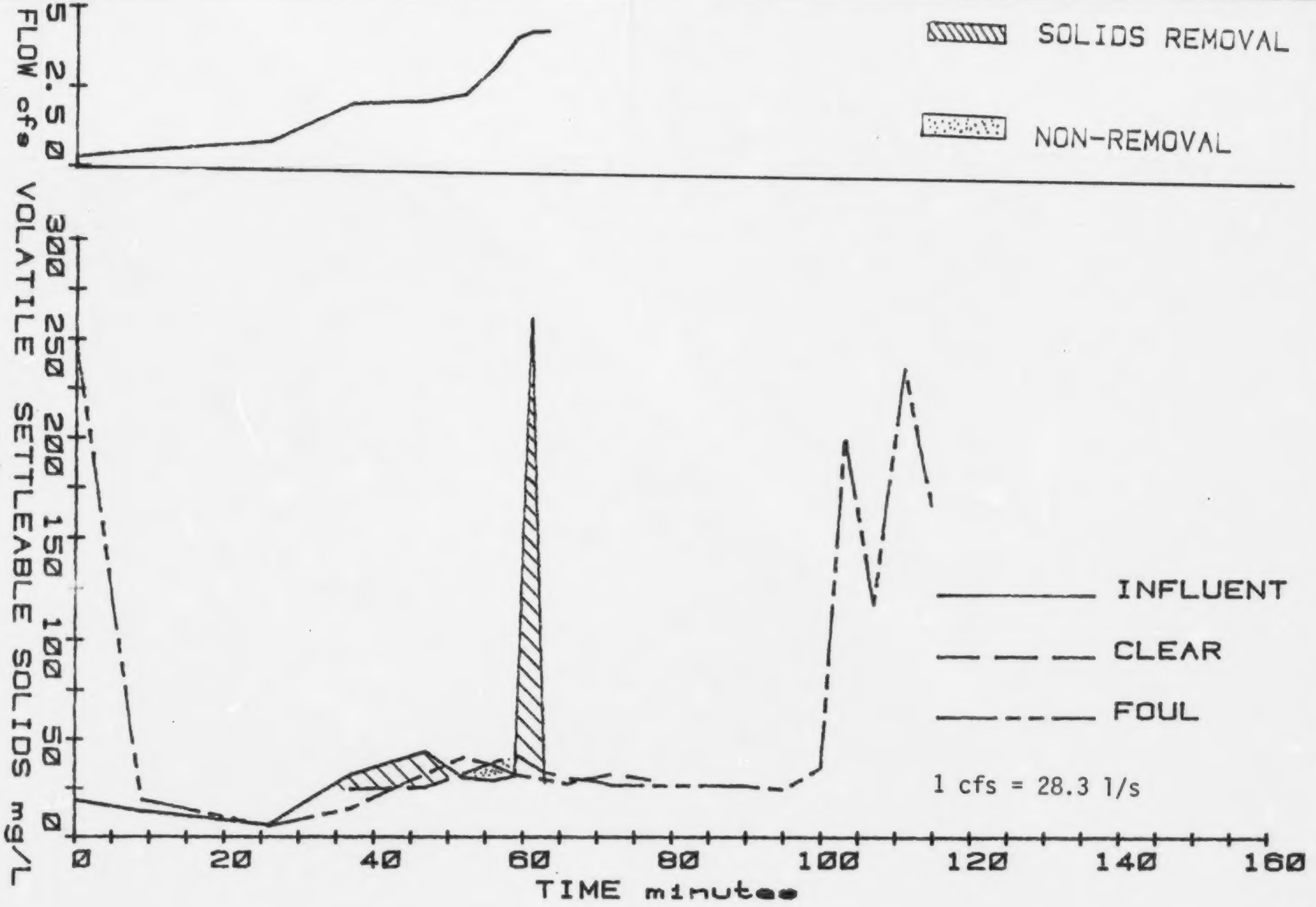


Figure 141. Volatile settleable solids concentrations vs time, W. Roxbury Helical Bend Regulator (10/25/80).

2.7 over an 80 minute period indicating solids concentrating effect. The influent flow ranged from 2 to 4 cfs (56.4-112.8 l/s) and the solids concentration fluctuated between 50 and 150 mg/l. Average suspended solids removal and efficiency rates are estimated at 29.7% and 21.4% based on an average flow of 3 cfs (85 l/s) and foul concentration factor of 2.05.

Average suspended solids removal and efficiency rates for the Helical Bend Regulator are estimated at 36.5% and 26.5% for an average flow rate of 2.5 cfs (70.5 l/s).

## 6/9/81 Results Summary

Plots of time vs influent, clear and foul sewer pollutant concentrations of suspended solids and settleable solids are presented in Figures 142 and 143 respectively for the Swirl Concentrator and in Figures 144 and 145 respectively for the Helical Bend Regulator.

During this event Swirl foul samples indicated no removals as all concentrations were less than influent values and minimal final drawdown flush was observed. Heavy solids deposits were observed in the Swirl tank floor near the foul sewer outlet at the end of operation. Based on a representative square foot sample, the total approximate solids debris in the tank was 26.5 lb (12 kg) of which 25% were volatile solids.

Based on clear overflow sample concentrations, the Swirl removal rate was 27% removal rate at 3 cfs (85 l/s) and 34% at 0.8 cfs (23 l/s) after 30 minutes. Corresponding unit efficiencies were 21% and 4% respectively. These results demonstrate the effect of influent rate on unit efficiency. Although the removal rate is higher at 0.8 cfs (23 l/s) the actual efficiency is greater at the higher flow rate since less flow-splitting occurs. After 30 minutes the influent flow remained below 1 cfs (28.2 l/s) and the influent solids concentration decreased continually.

Based on clear overflow samples no removals occurred for the Helical Bend during the first 15 minutes. From 15 to 45 minutes the unit averaged 41% removal rate at an influent rate of 0.8 cfs (22.6 l/s). The efficiency equalled 10% at this flow rate. However, considering the foul sewer the average foul concentration factor was 1.12 indicating a removal rate of 50% and an effciency of 19% over 60 minutes followed by a highly concentrated final flush.

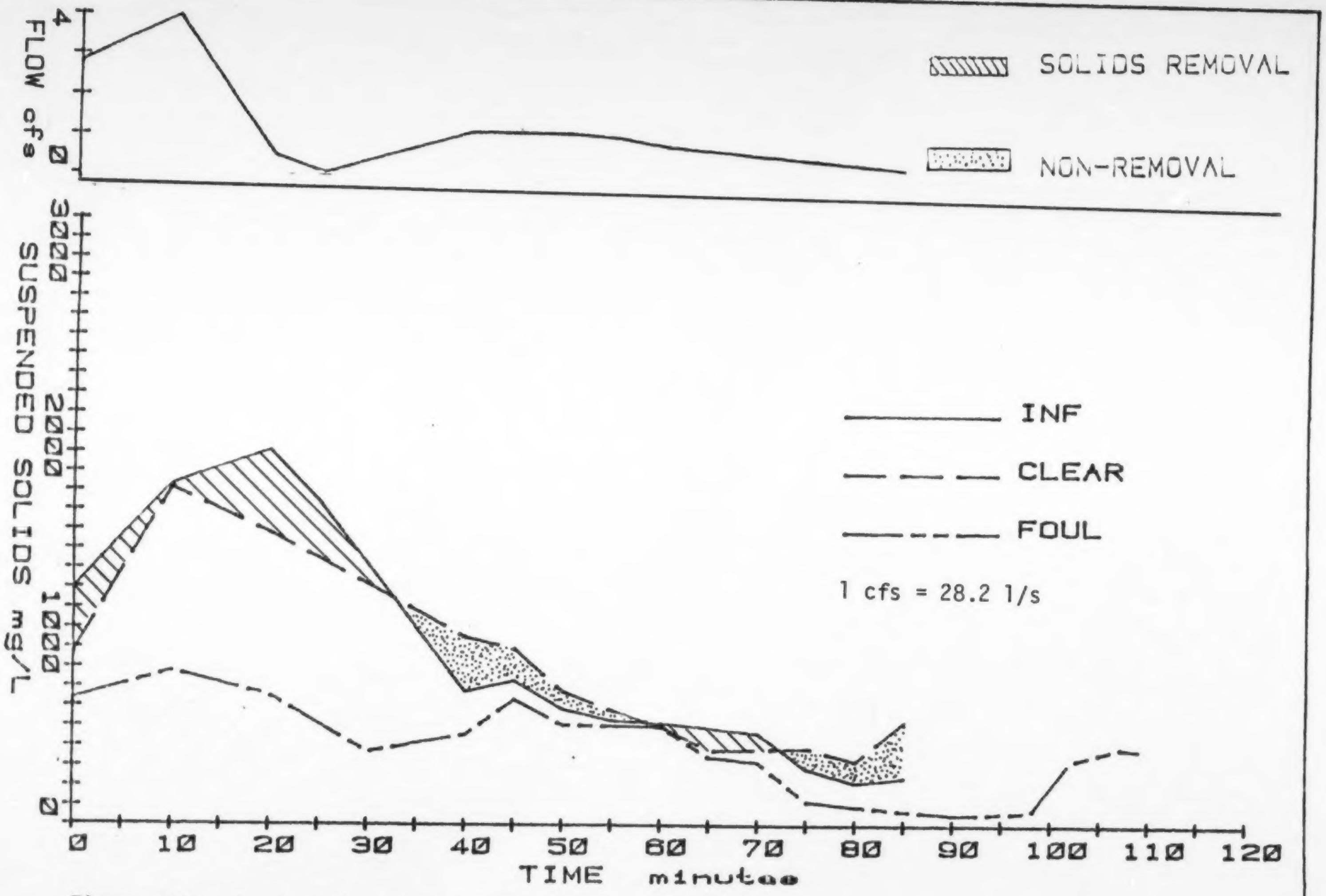


Figure 142. Suspended solids concentrations vs time, West Roxbury Swirl (6/9/81).

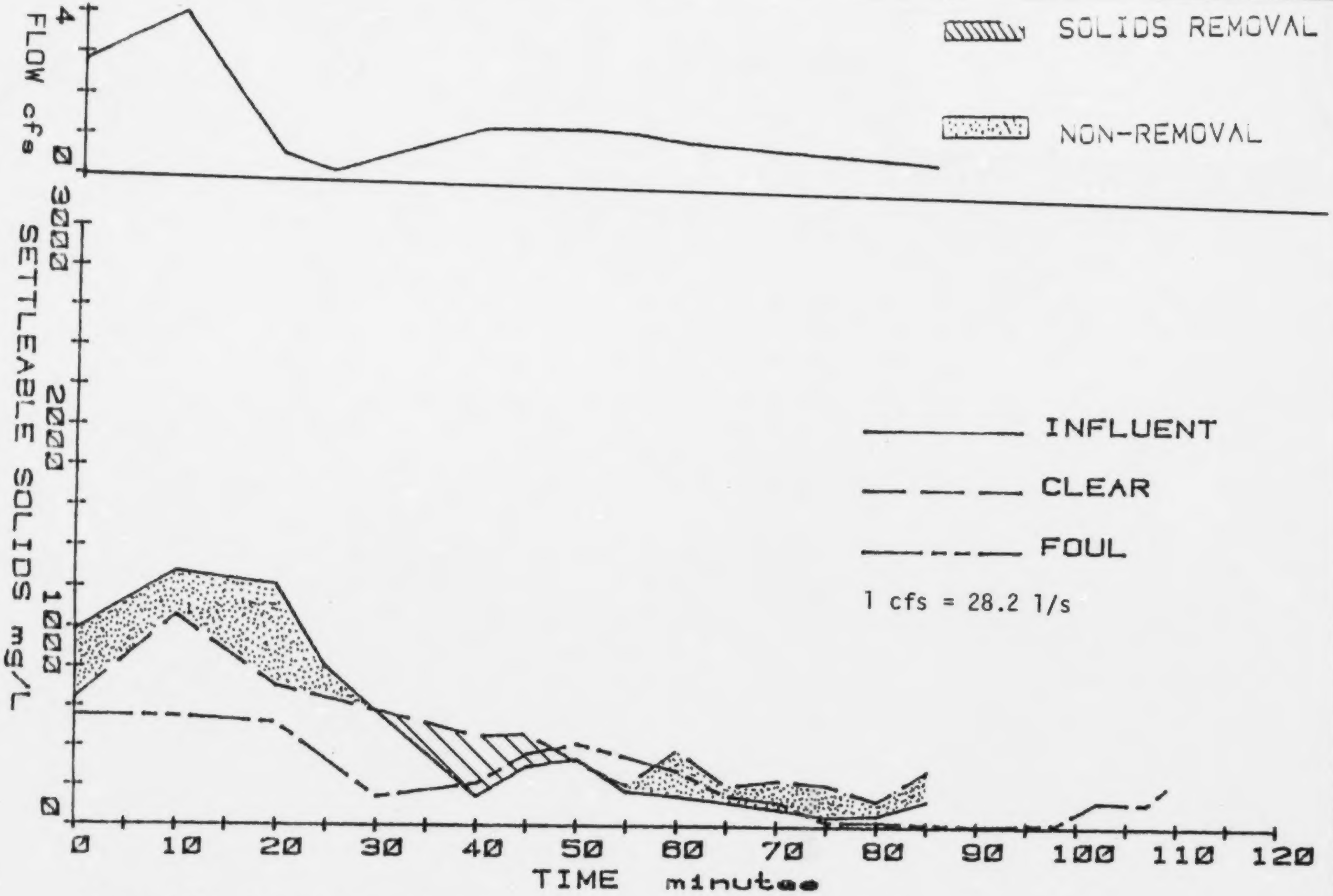


Figure 143. Settleable solids concentrations vs time, West Roxbury Swirl (6/9/81).

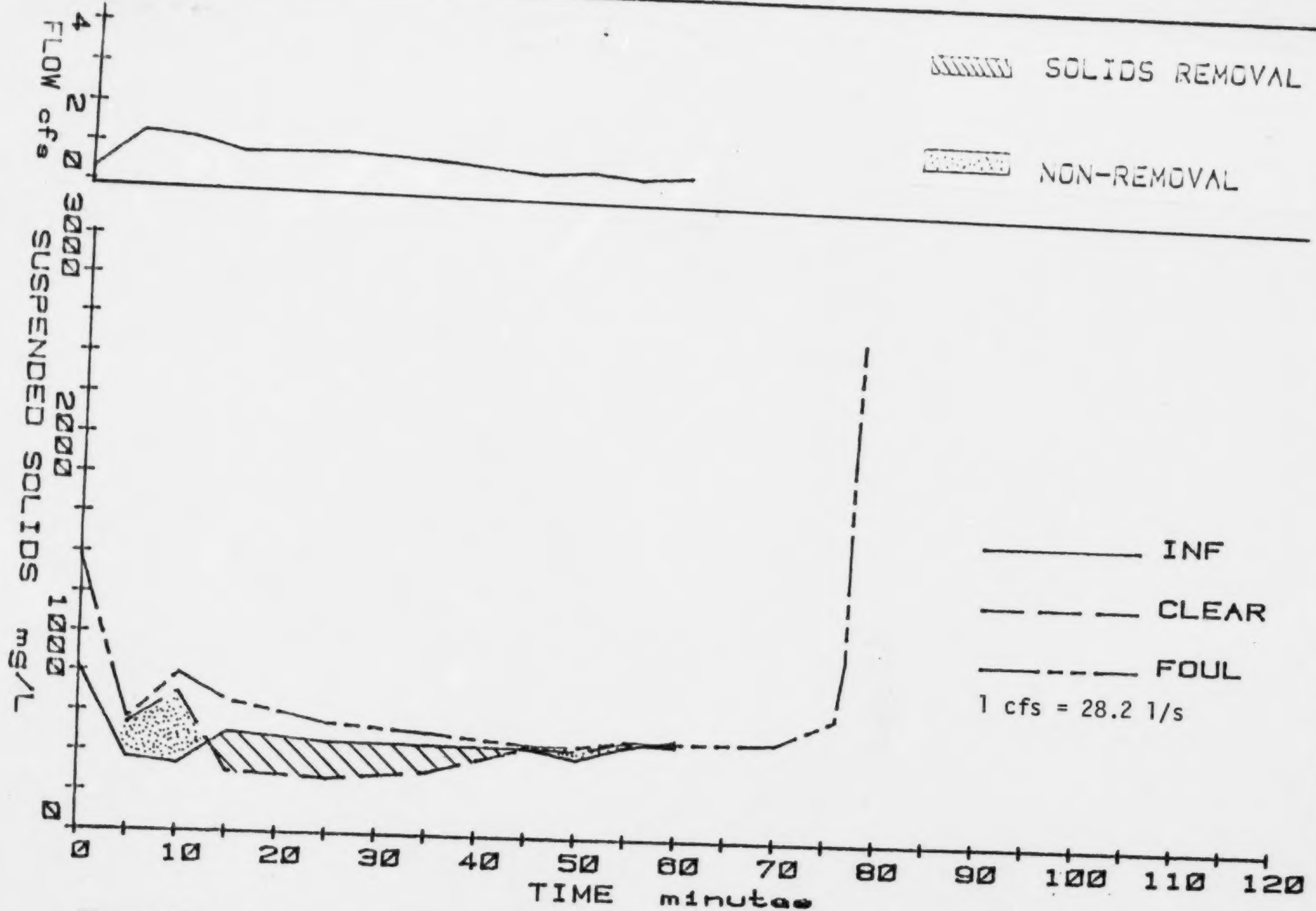


Figure 144. Suspended solids concentrations vs time, West Roxbury Helical (6/9/81).

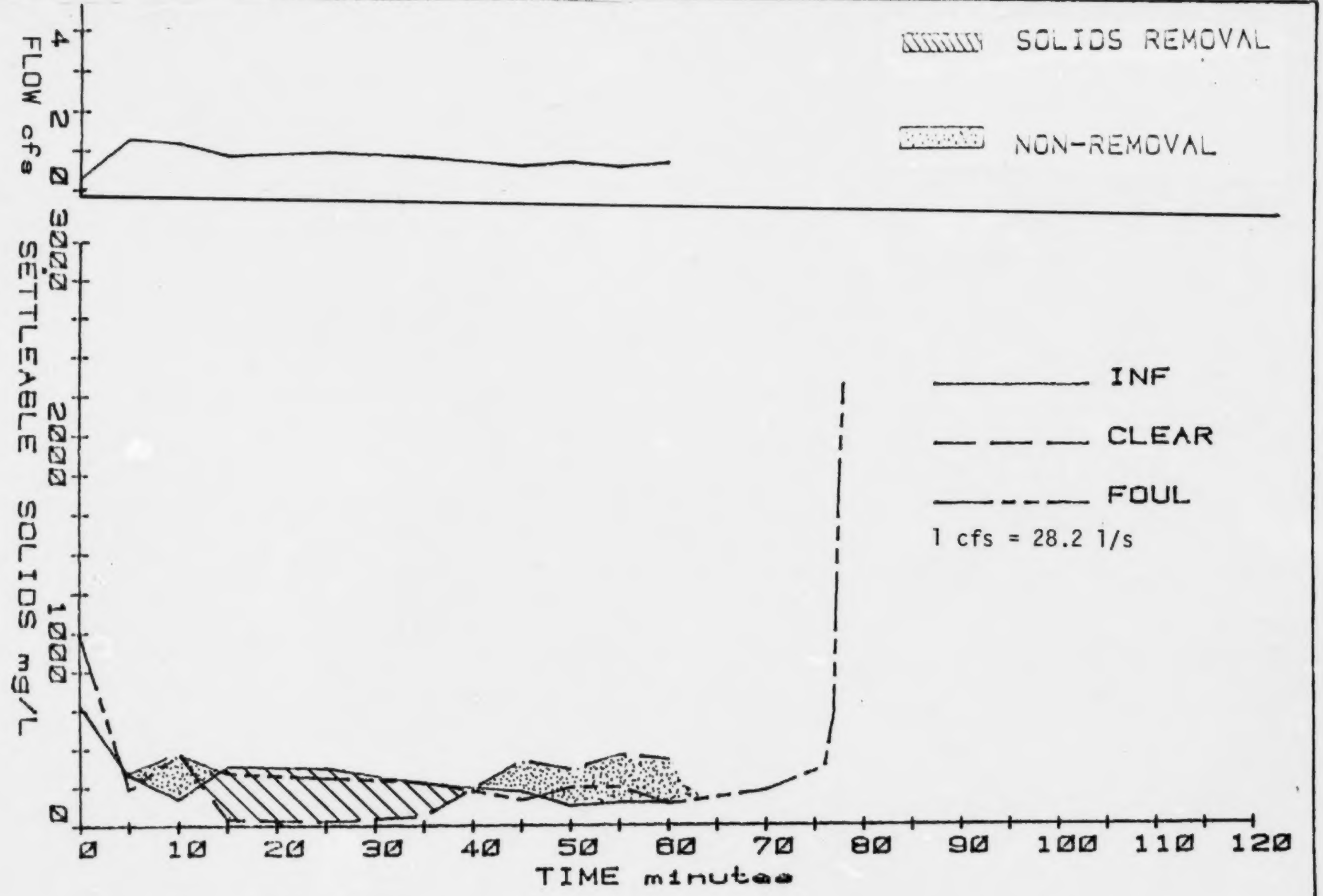


Figure 145. Settleable solids concentrations vs time, West Roxbury Helical (6/9/81).

Solids remaining in the unit following this event were concentrated at the last 12 ft (3.65 m) of the unit. A representative sample was taken 5 ft (1.5 m) from the discharge line approximately 1 $ft^2$ (0.09 $m^2$) in area. The total solids residue in the unit was calculated to be 16.5 lb (7.5 kg) of which 35% is volatile solids. Photographs of the Helical Bend Regulator during and after the event are shown in Figure 146.

## 6/22/81 Removal Results

Plots of time vs influent, clear and foul sewer pollutant concentrations of suspended solids, volatile suspended solids, settleable solids and volatile settleable solids are presented in Figures 147-150 respectively for the Swirl Concentrator, and in Figures 151-154 respectively for the Helical Bend Regulator.

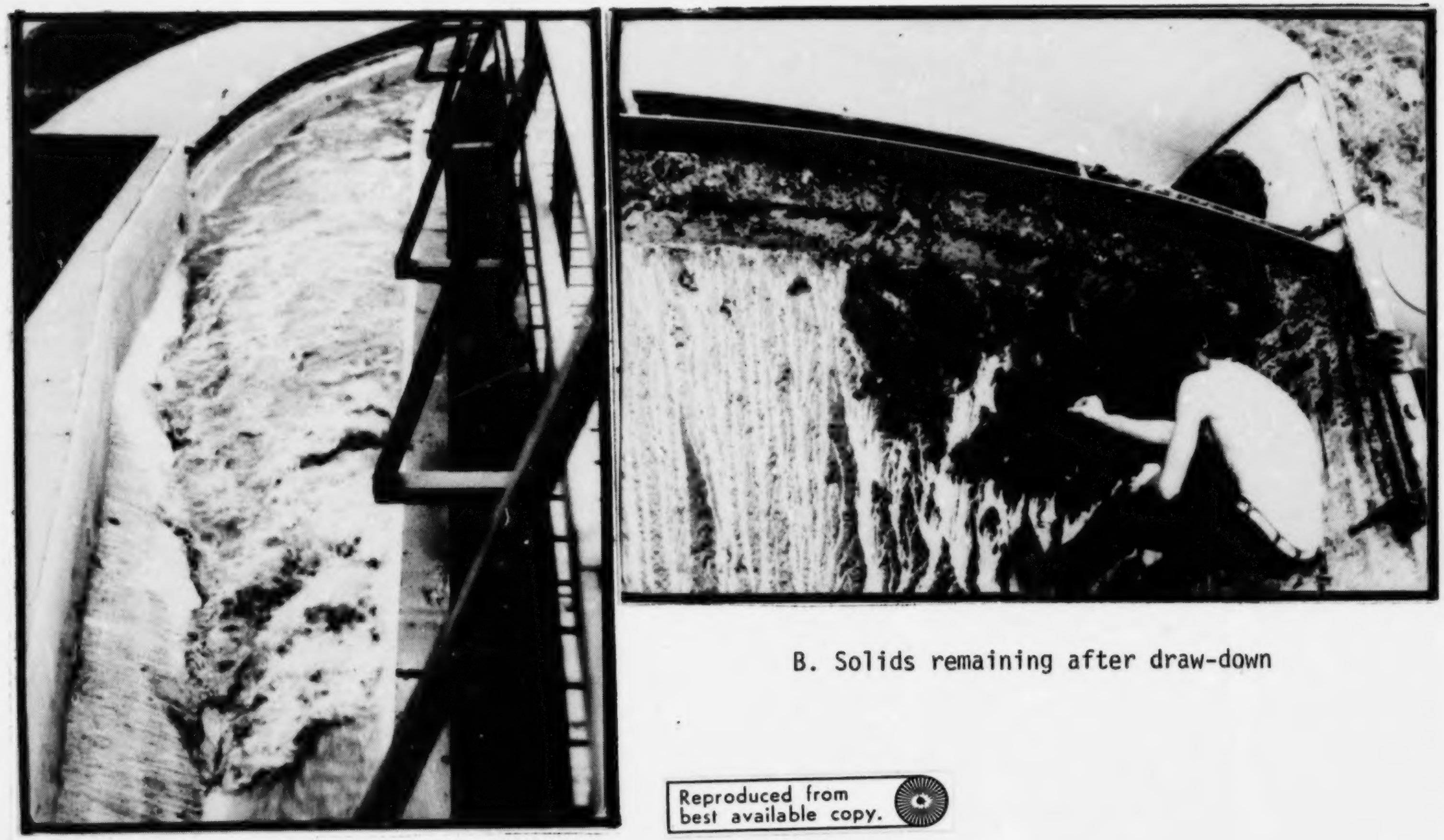
During the first 15 minutes of this event no Swirl removals are observed by relating influent to clear concentrations. Influent flow averaged 2.2 cfs (62 l/s) with an average foul concentration factor of 1.2. Foul rate was 0.25 cfs (7 l/s). Based on foul flow data an average removal rate of 27 % and efficiency of 16% were calculated. For the remaining 15 minutes of evaluation clear samples indicated an average removal rate of 33% and efficiency of 21% at a flow of 2 cfs (56.6 l/s). Foul samples indicated no removal although a final drawdown /flush was observed.

The Helical Bend showed negative removals using clear sample data. The average foul concentration factor was 1.43 using an average flow rate of 1.8 cfs (51 l/s). Based on foul flow data, an average removal rate of 35% and an average efficiency rate of 21.5% were calculated.

## 8/4/81 Removal Results

Plots of time vs influent, clear and foul sewer pollutant concentration of suspended solids, volatile suspended solids, settleable solids and volatile settleable solids are presented in Figures 155-158 respectively for the Swirl Concentrator and in Figures 159-162 respectively for the Helical Bend Regulator.

The Swirl average removal and efficiency rates equalled about 6% based on clear sample values during the time of stable flow at 12.3 cfs (340 l/s). Prior to this point no removals were indicated on a clear sample basis. As the flow approached the design rate of 6 cfs (170 l/s) the removal rate increased to an average of 9.5% while the efficiency was calculated to be 55% considering the foul sewer data.



A. View from influent end

B. Solids remaining after draw-down

Reproduced from best available copy.

Figure 146. Photographs of the Helical Bend Regulator operation, (6/9/81).

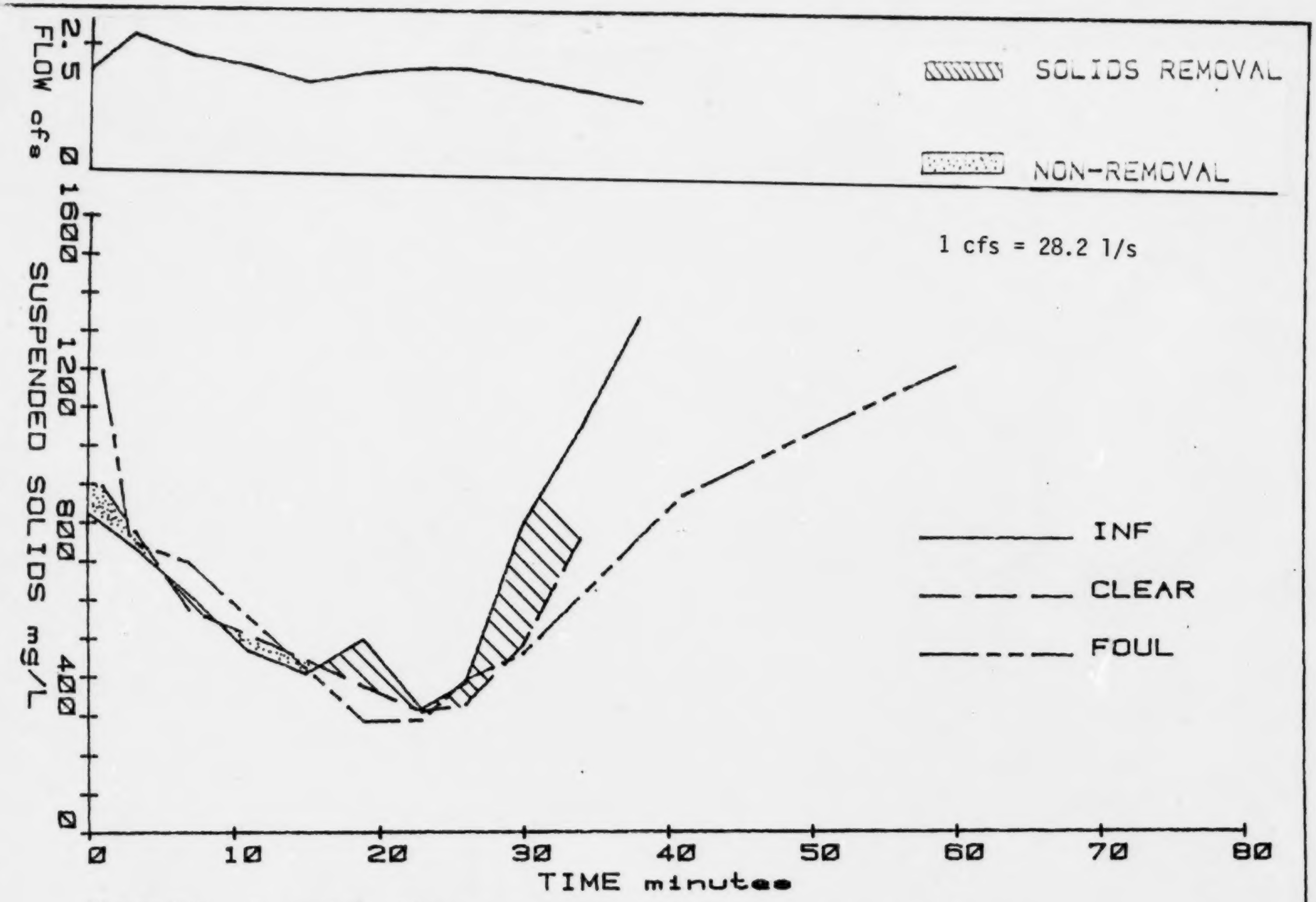


Figure 147. Suspended solids concentrations vs time, West Roxbury Swirl (6/22/81).

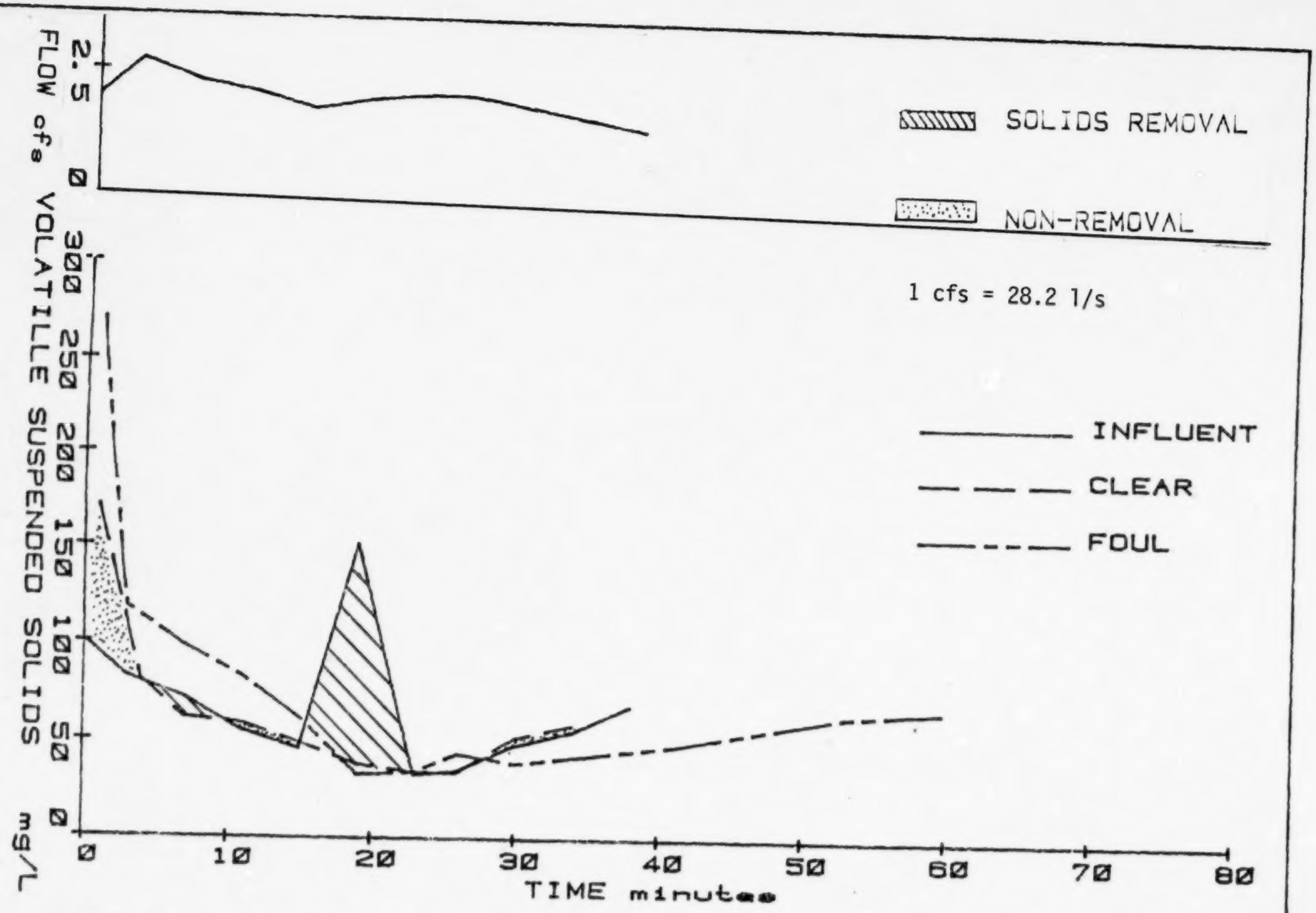


Figure 148. Volatile suspended solids concentrations vs time, West Roxbury Swirl (6/22/81).

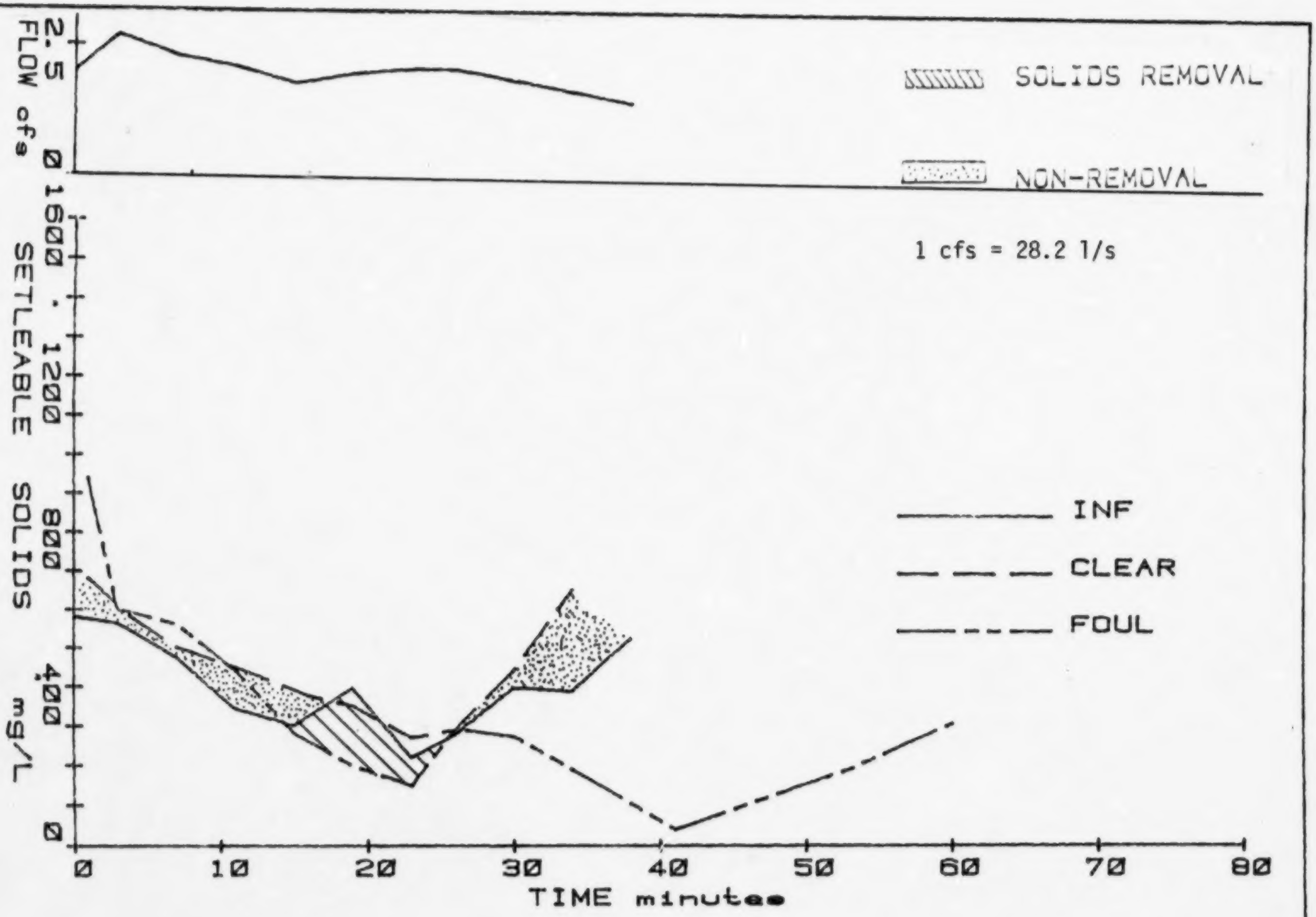


Figure 149. Settleable solids concentrations vs time, West Roxbury Swirl (6/22/81).

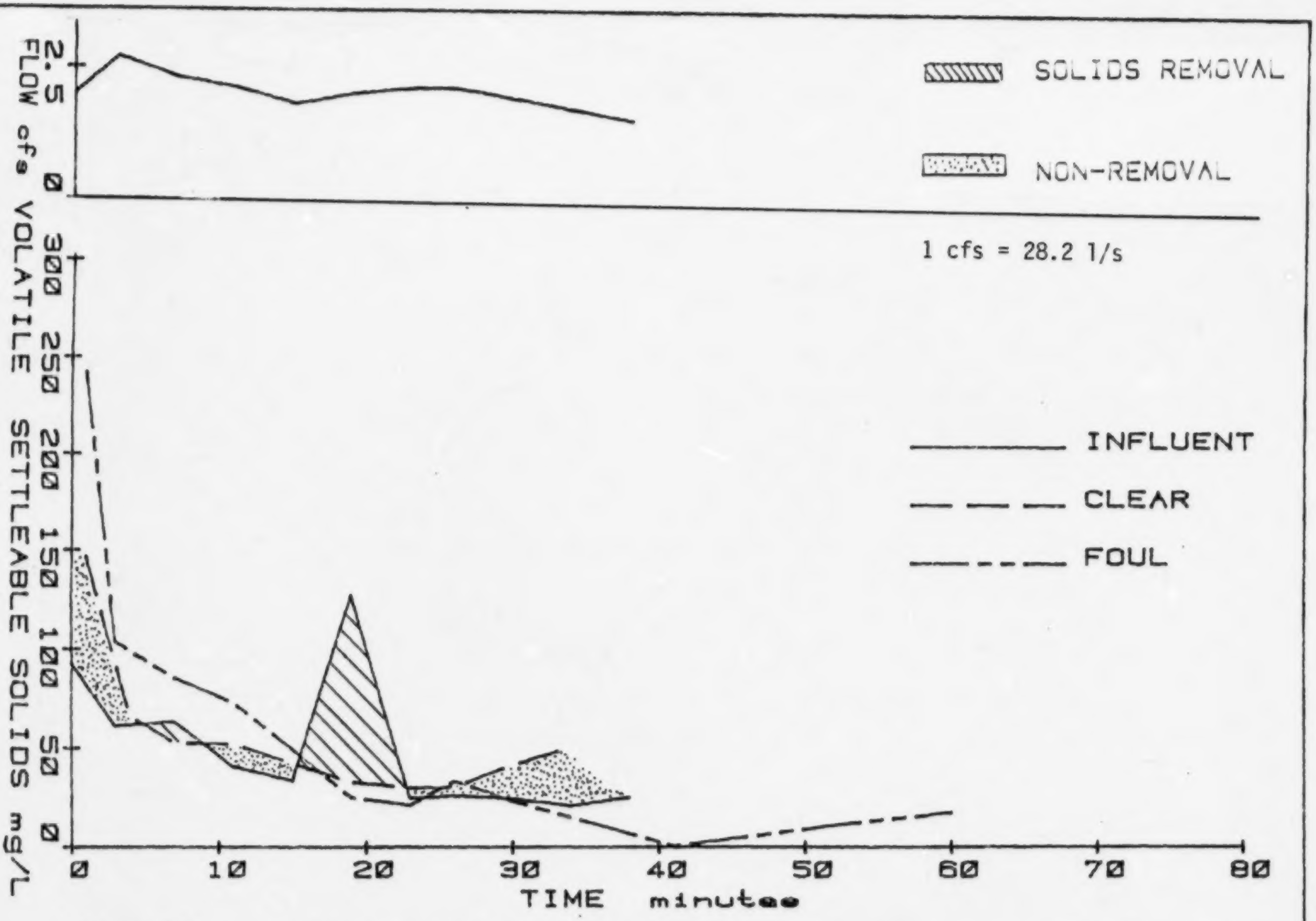


Figure 150. Volatile settleable solids concentrations vs time, West Roxbury Swirl (6/22/81).

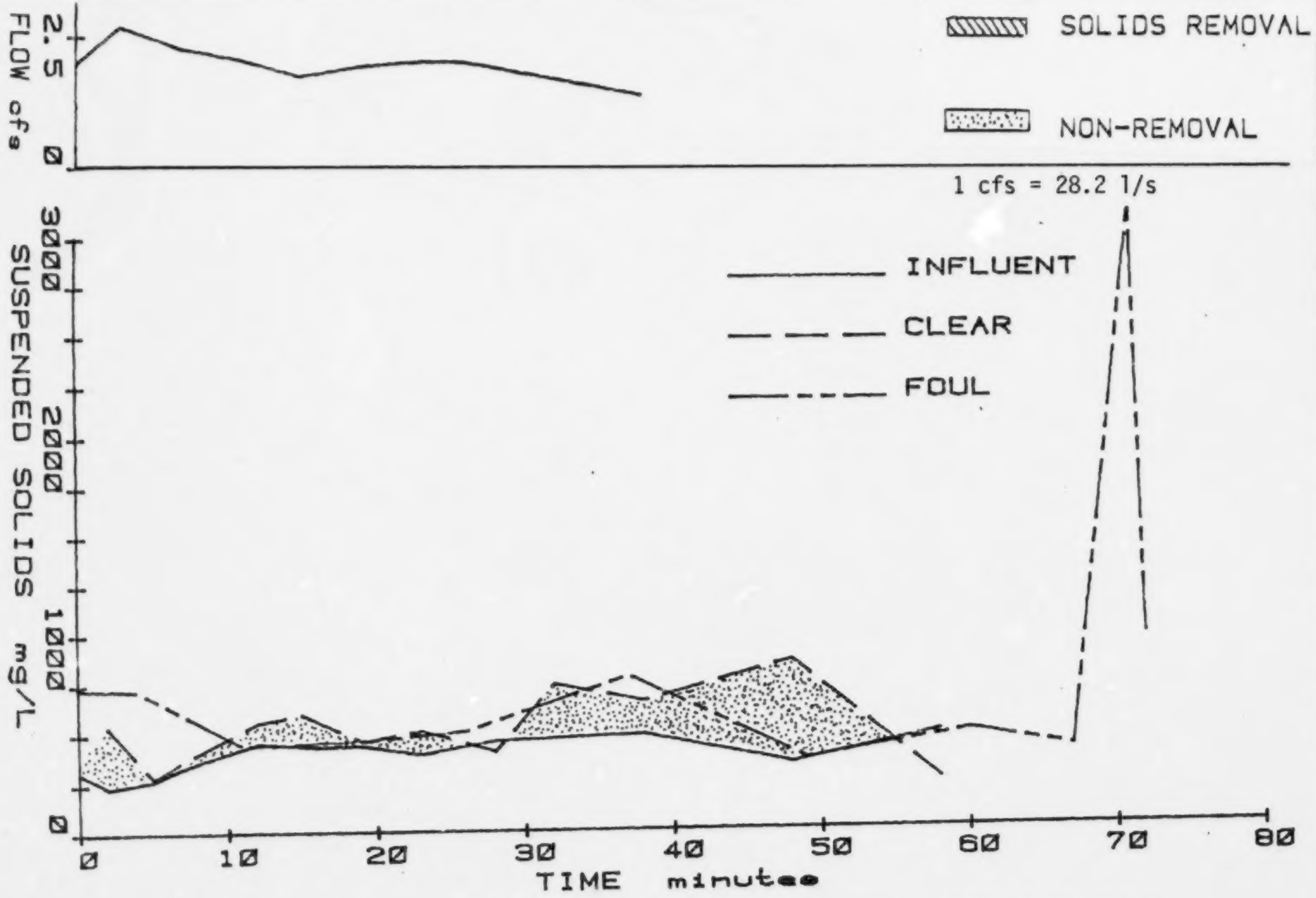


Figure 151. Suspended solids concentrations vs time, West Roxbury Helical (6/22/81).

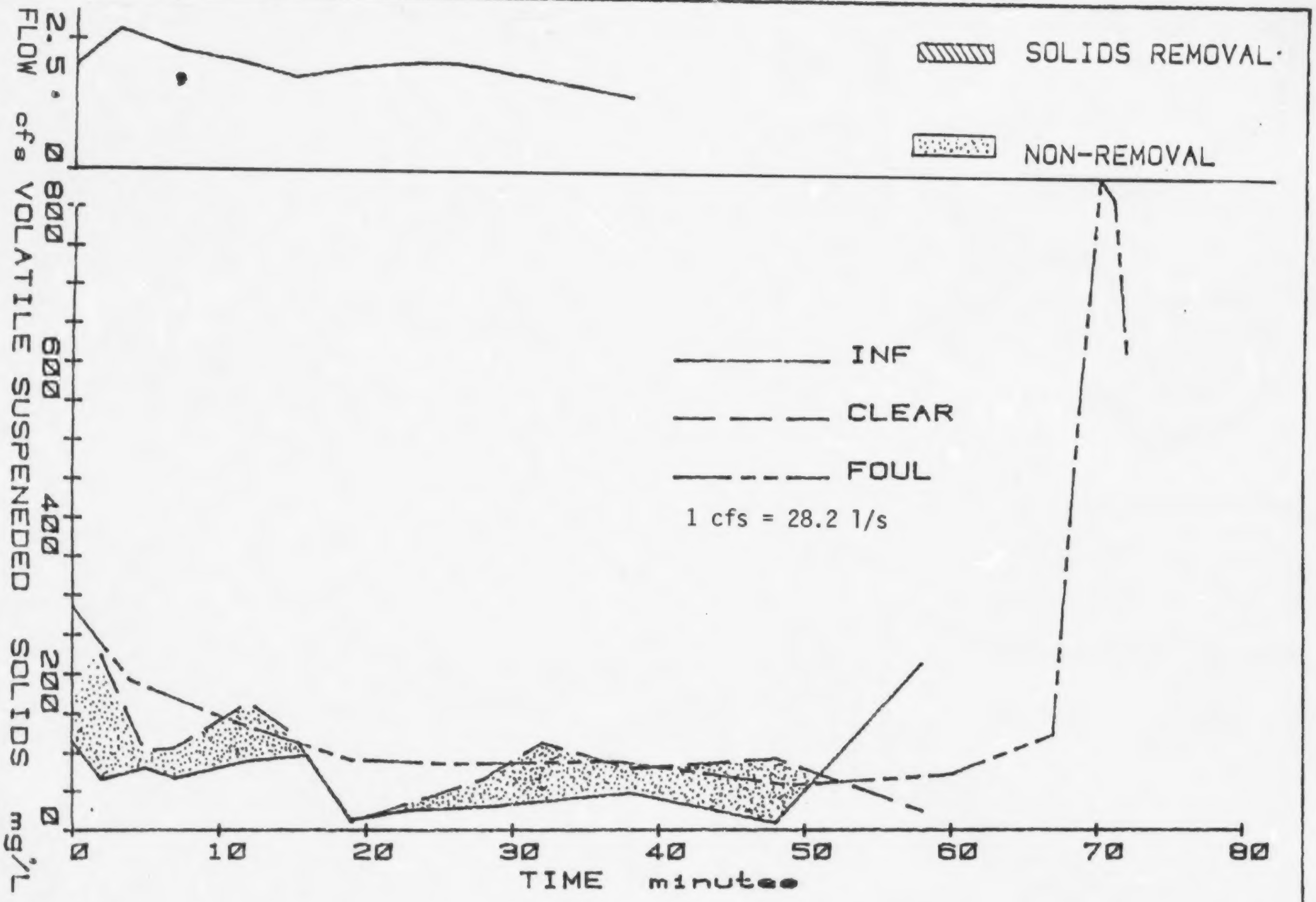


Figure 152. Volatile suspended solids concentrations vs time, West Roxbury Helical (6/22/81).

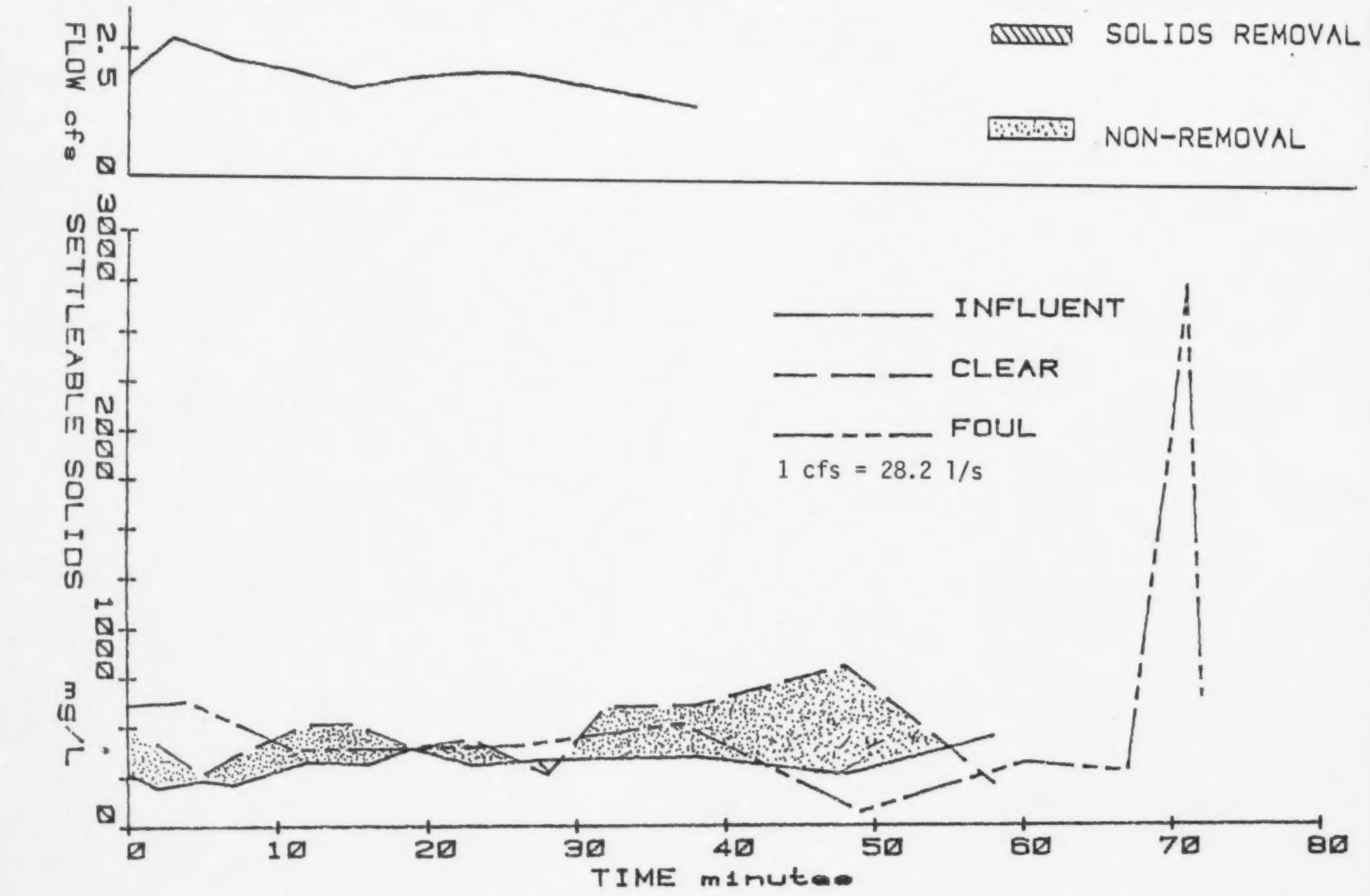


Figure 153. Settleable solids concentrations vs time, West Roxbury Helical (6/22/81).

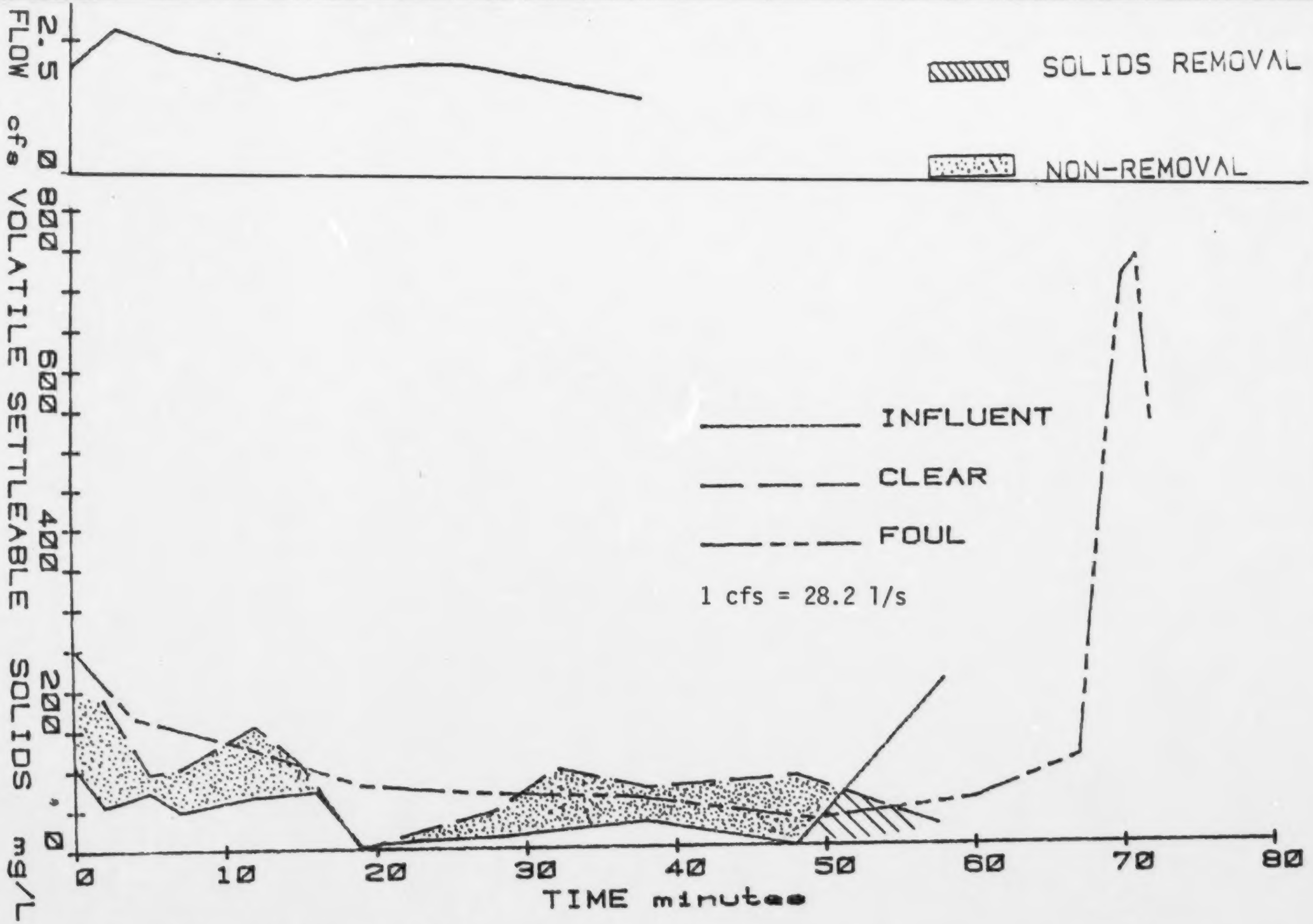


Figure 154. Volatile settleable solids concentrations vs time, West Roxbury Helical (6/22/81).

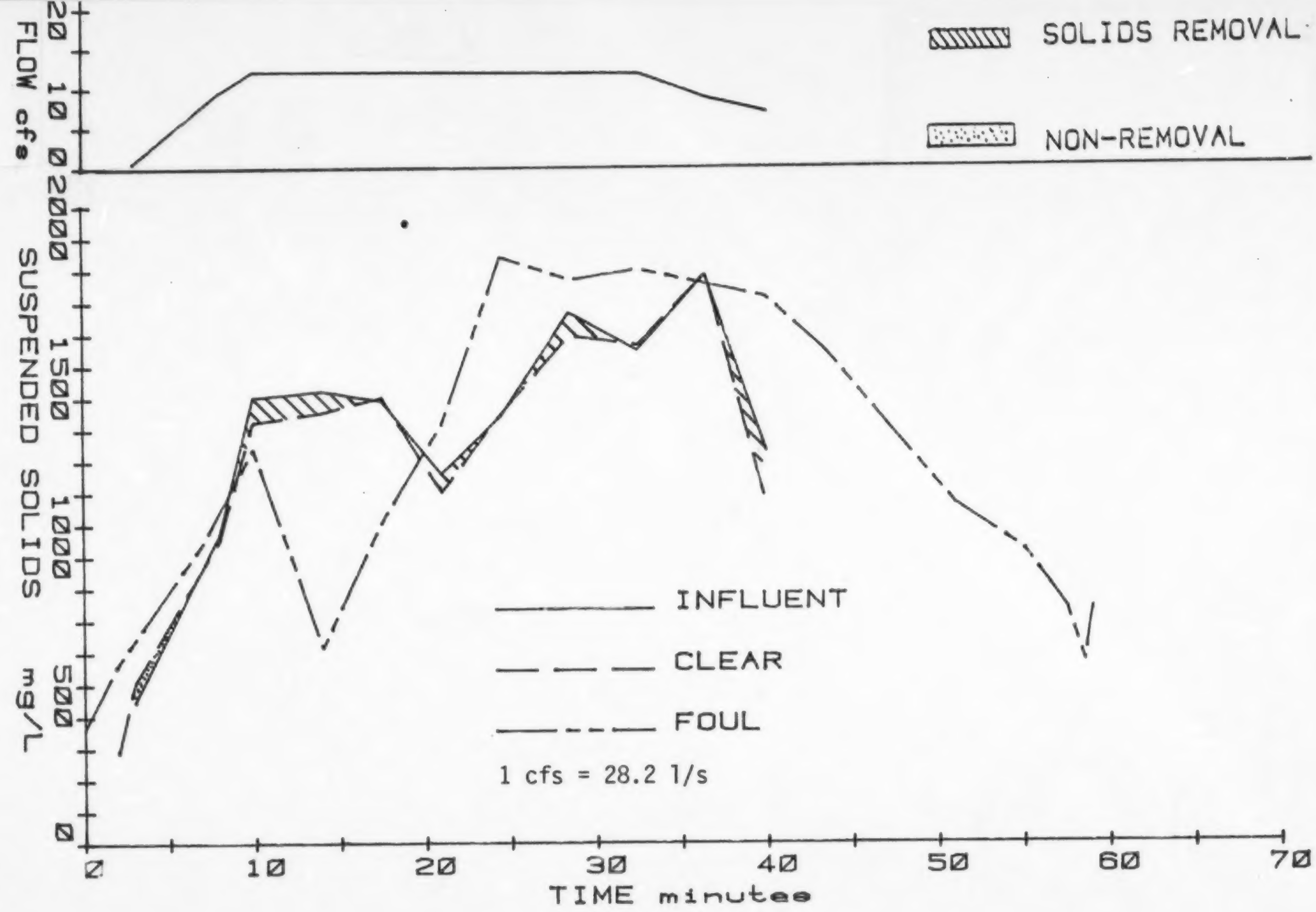


Figure 155. Suspended solids concentrations vs time, West Roxbury Swirl (8/4/81).

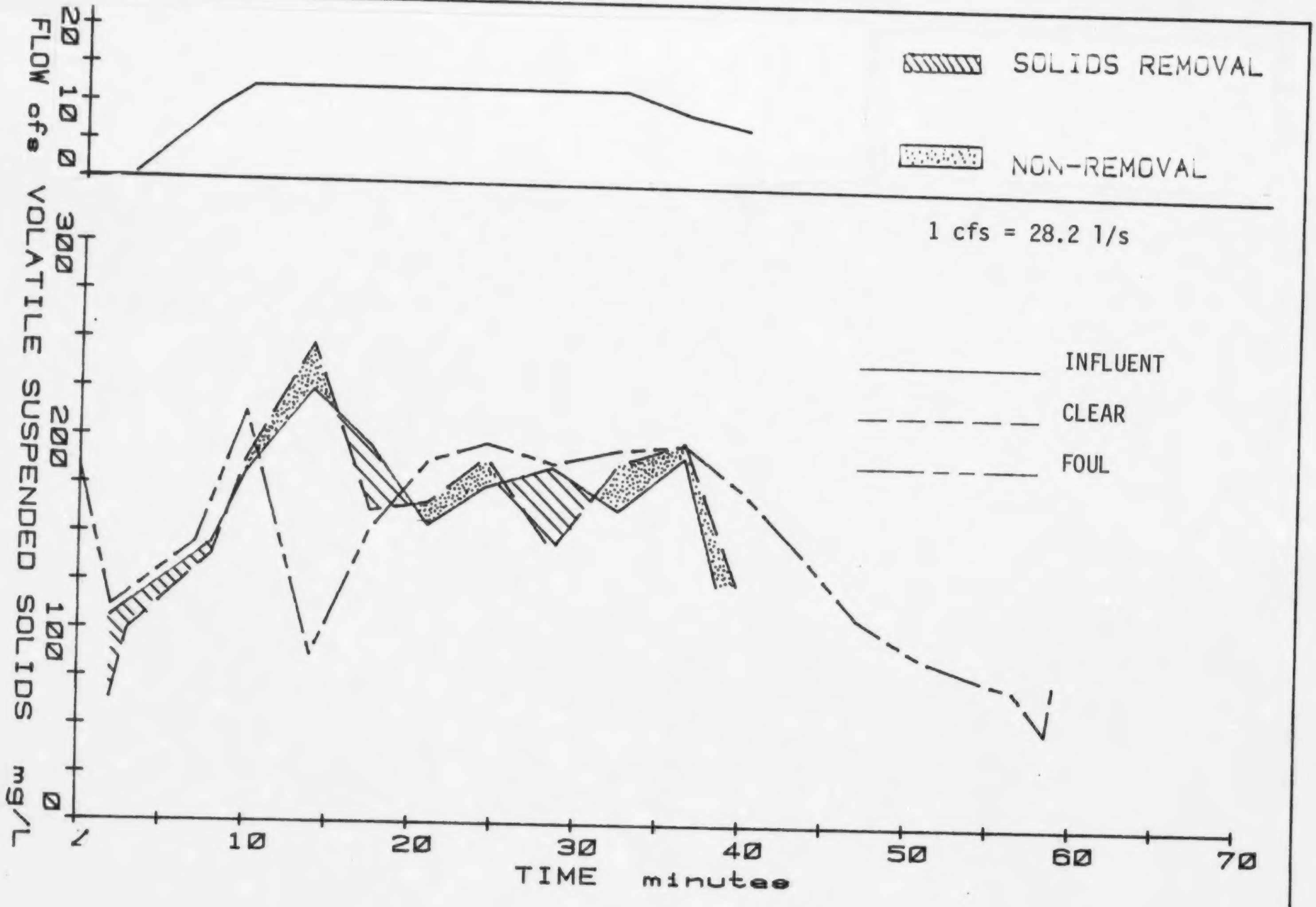


Figure 156. Volatile suspended solids concentrations vs time, West Roxbury Swirl 8/4/81.

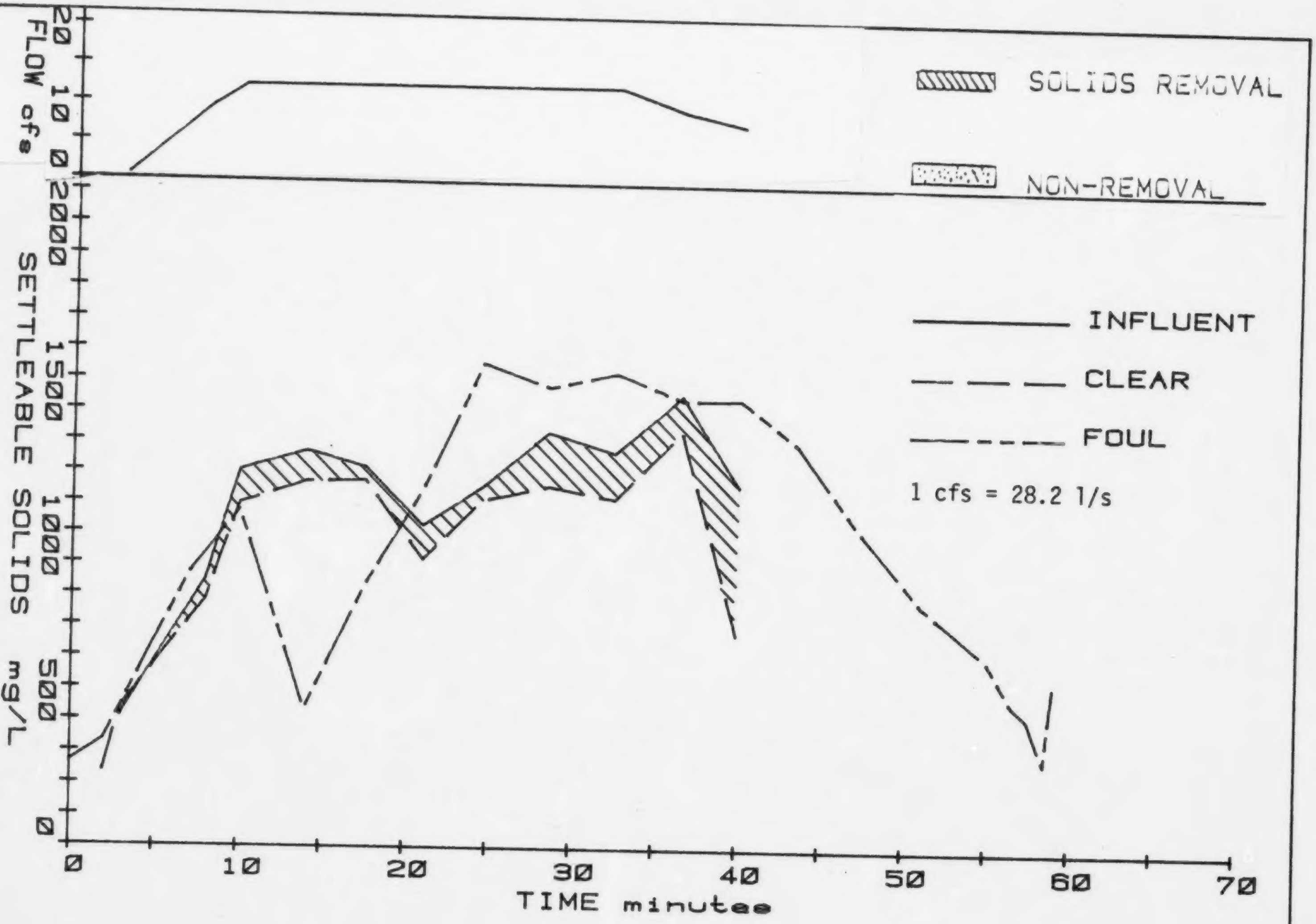


Figure 157. Settleable solids concentrations vs time, West Roxbury Swirl (8/4/81).

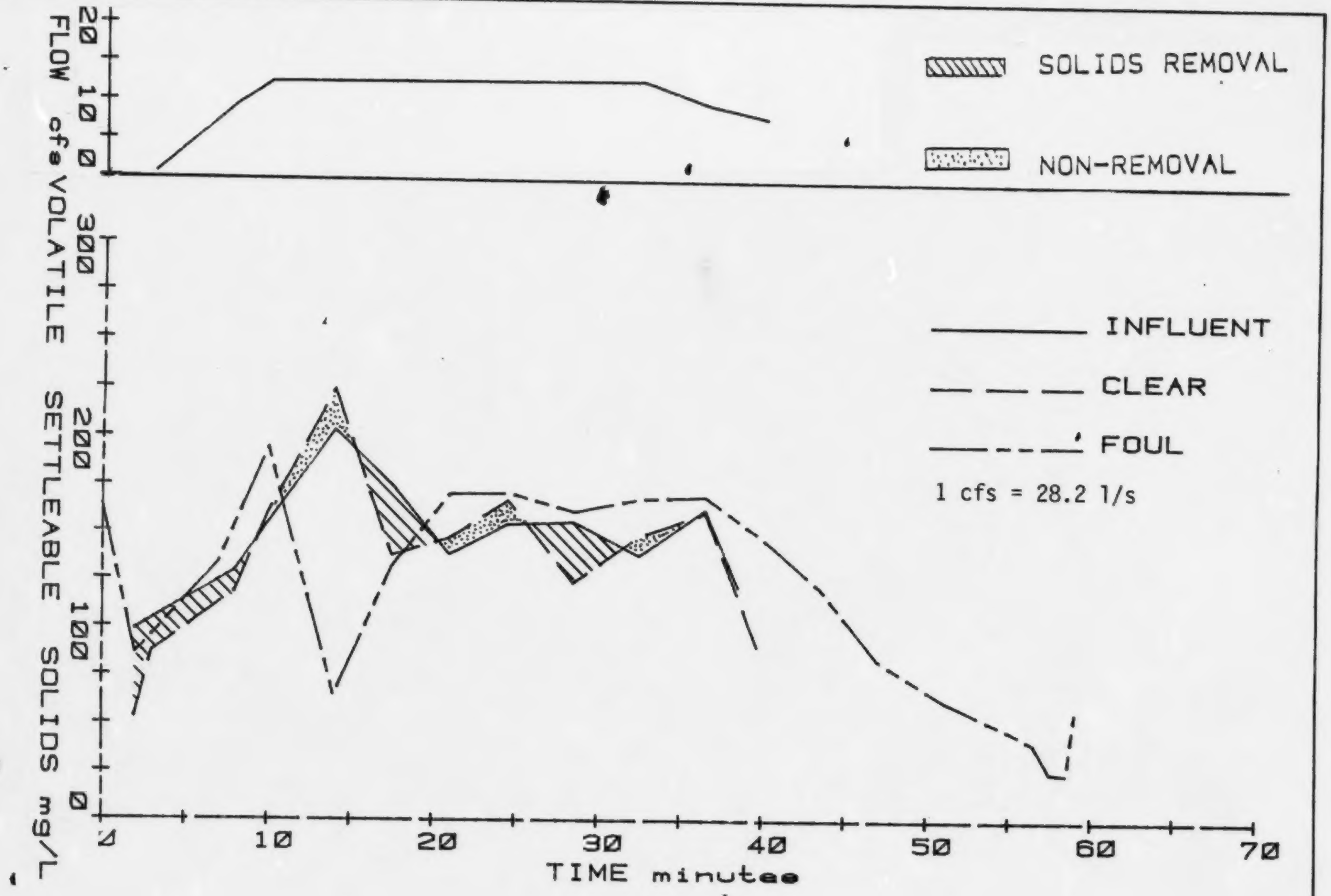


Figure 158. Volatile settleable solids concentrations vs time, West Roxbury Swirl (8/4/81).

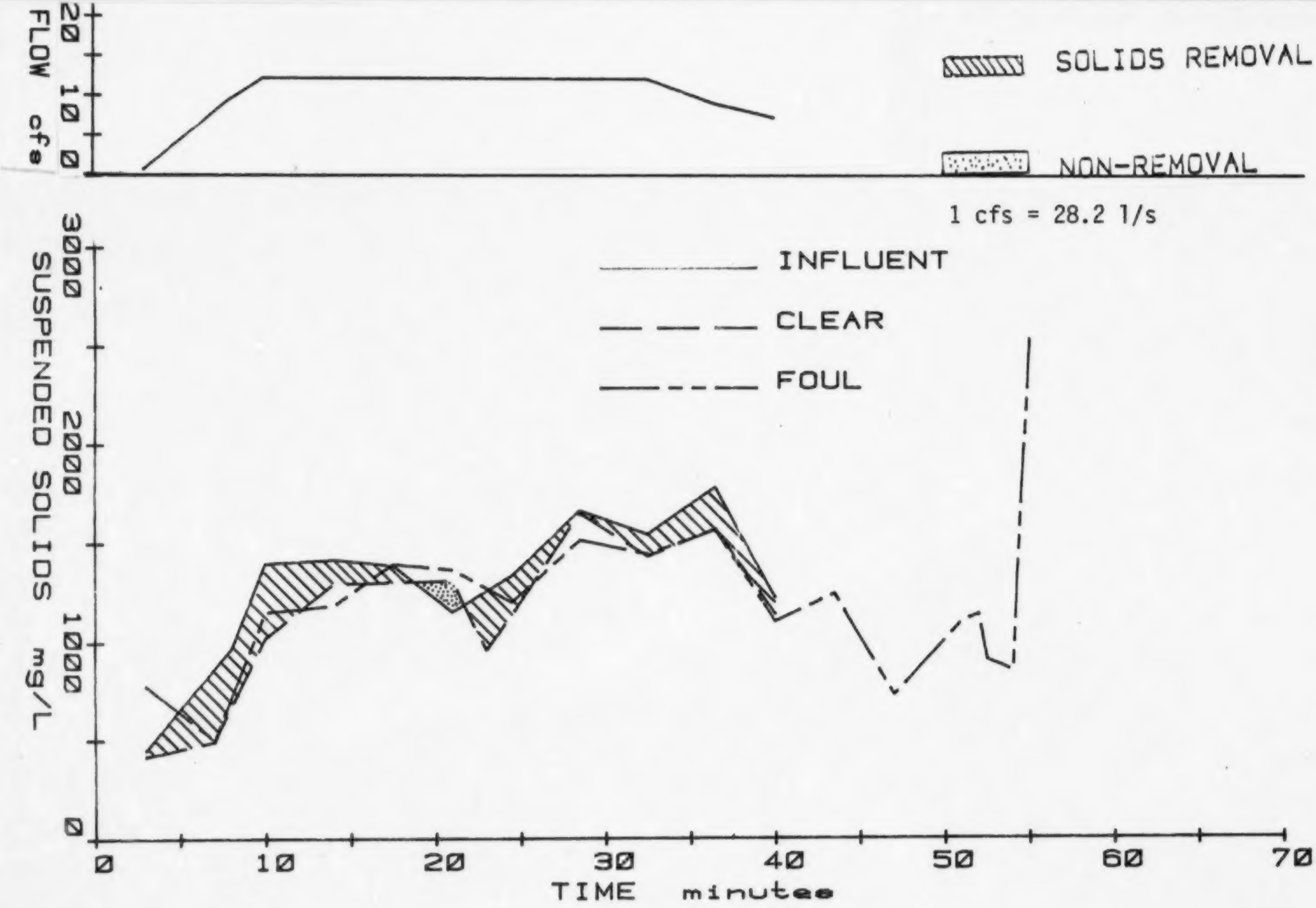


Figure 159. Suspended solids concentrations vs time, West Roxbury Helical (8/4/81).

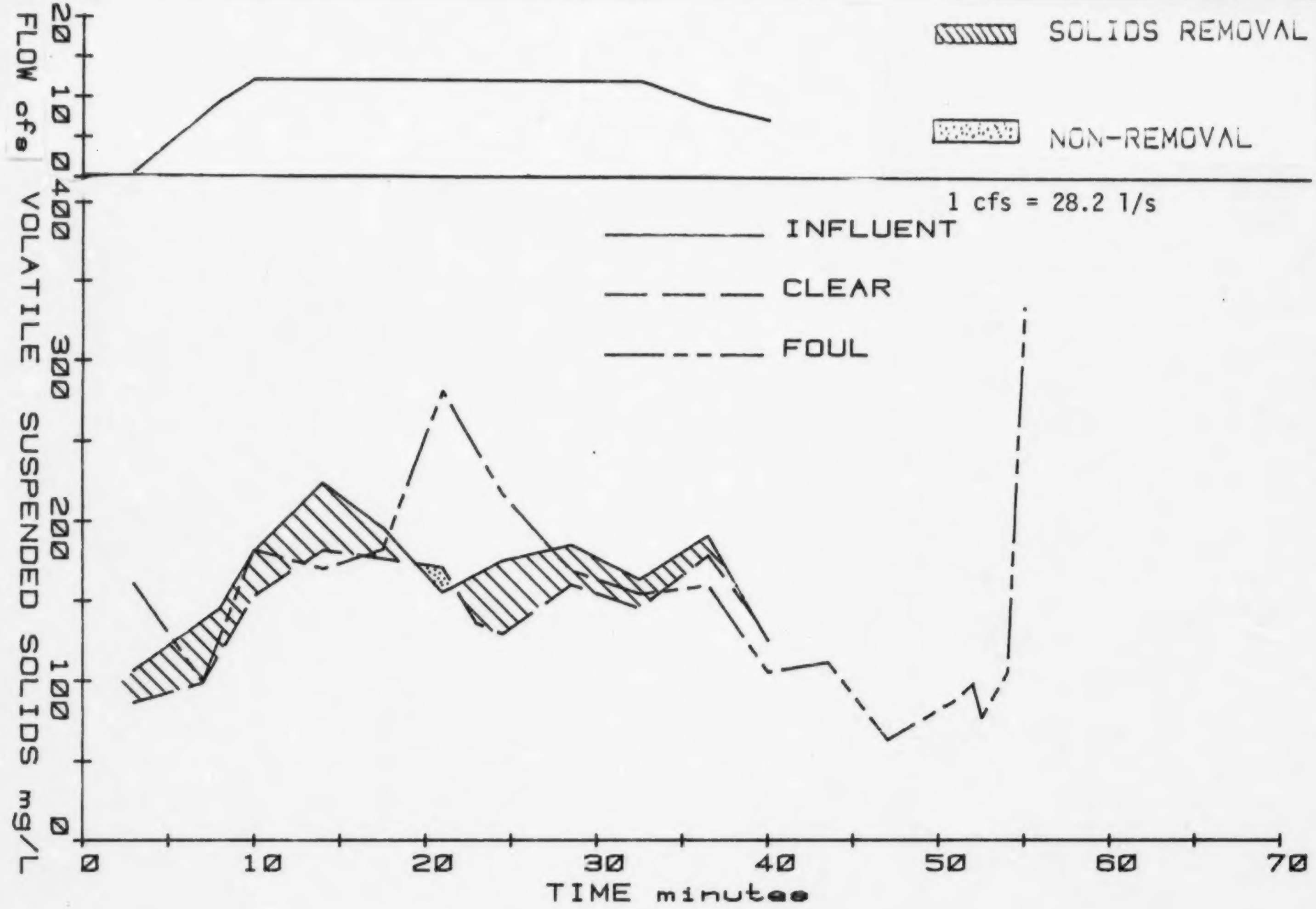


Figure 160. Volatile suspended solids concentrations vs time, West Roxbury Helical (8/4/81).

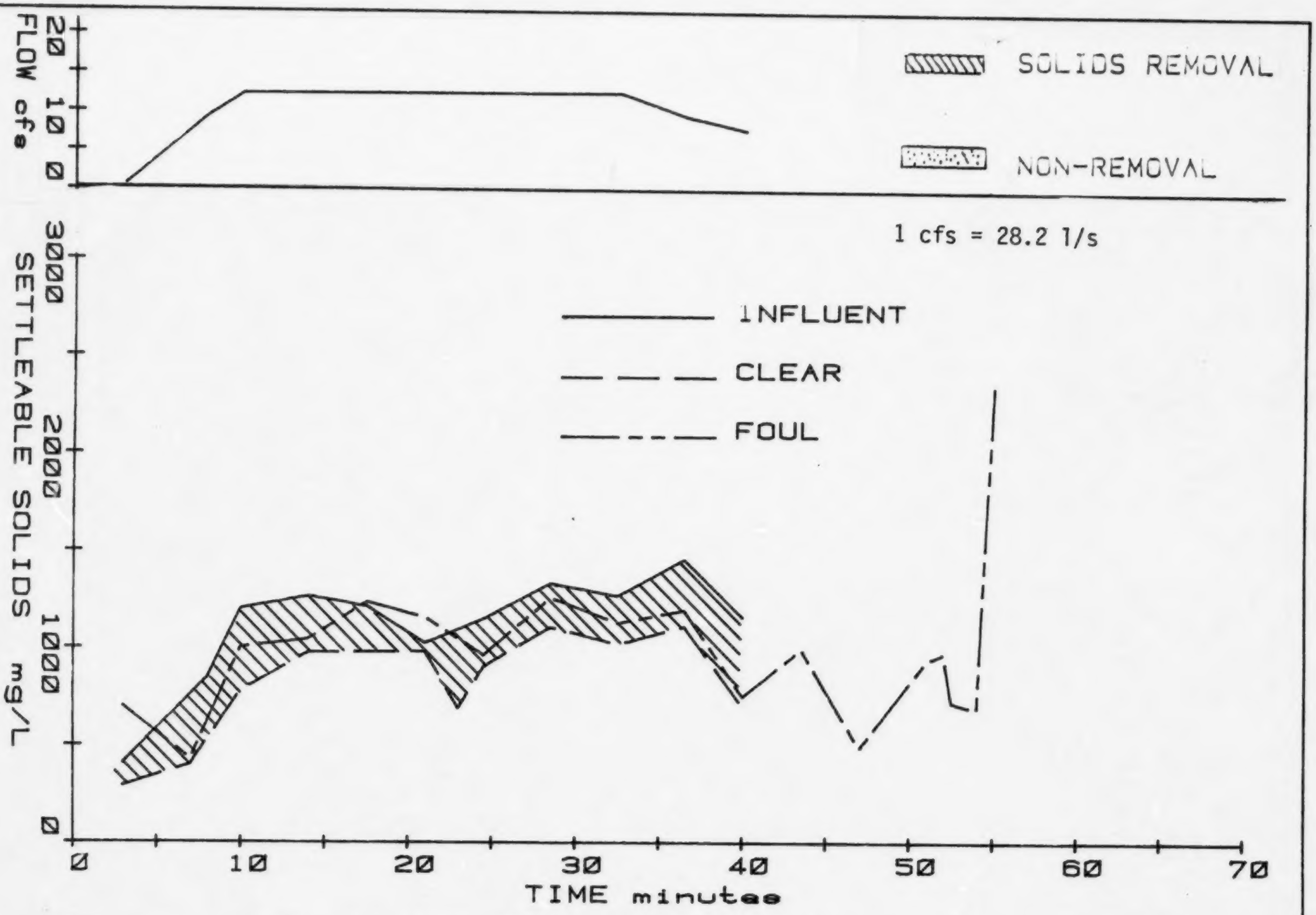


Figure 161. Settleable solids concentrations vs time, West Roxbury Helical (8/4/81).

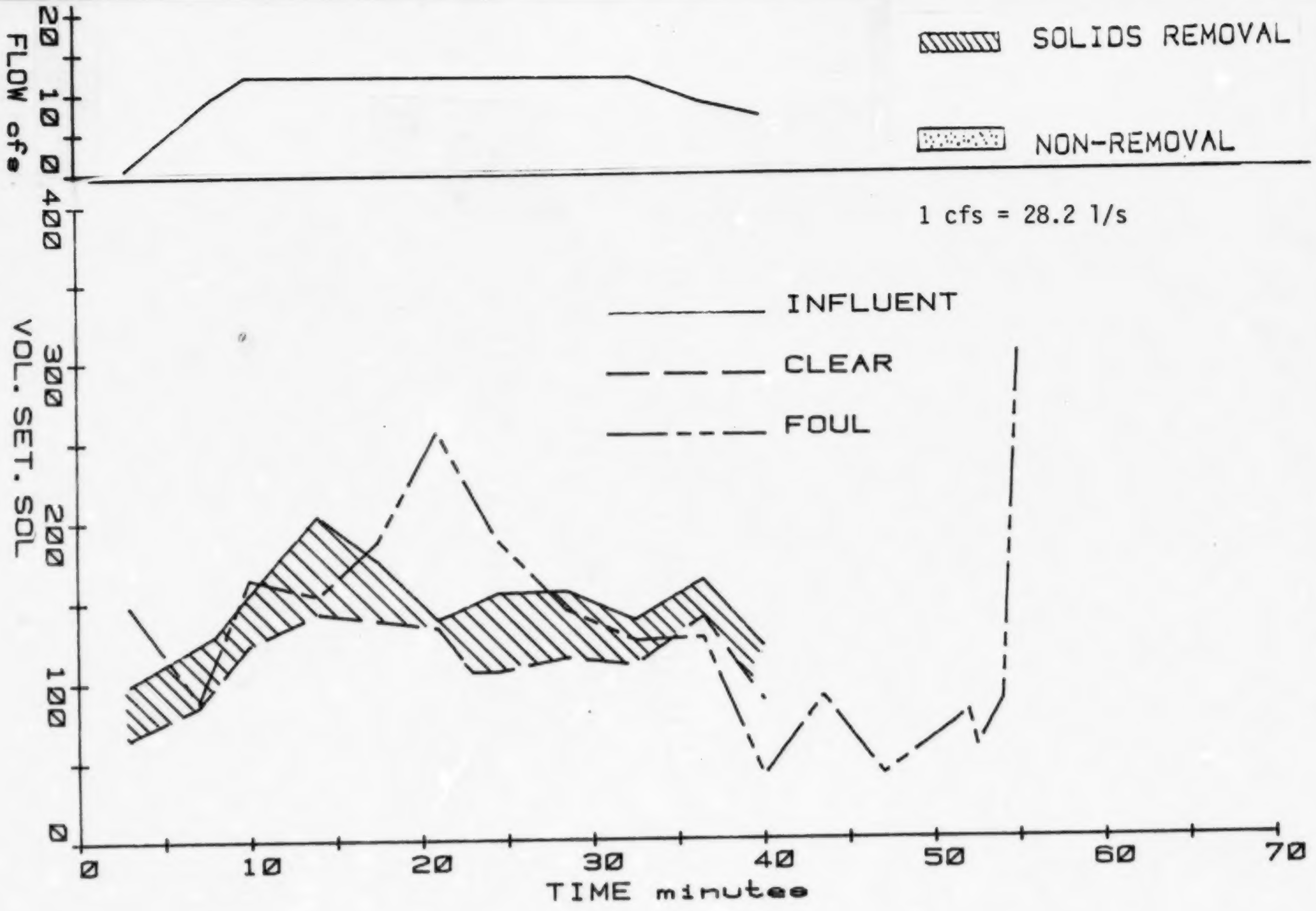


Figure 162. Volatile settleable solids concentrations vs time, West Roxbury Helical (8/4/81).

The Swirl removal rate averaged 6% over the first 10 minutes and averaged 4% for the last 23 minutes. Foul concentrations continued to decrease during tank drawdown due tc settling of materials resulting in a layer of solids on the tank bottom at the end of operation.

Analysis of clear sample concentrations for the Helical Bend indicated an average removal rate of 31% during the initial 10 minute period during which the flow increased from 0 to 12.3 cfs (341 l/s). Removal rates averaged 10.0% over the 27 minute period of constant flow at 12.3 cfs (341 l/s). Flow then decreased to 6 cfs (170 l/s) and the removal rate averaged 12.9%. Efficiencies during these three periods are 27.0, 8.0, and 8.9%, respectively.

Analysis of foul sewer data indicated no removal during operation but the drawdown period exhibited high solids concentrations and materials remained in the unit after operation.

## 13.4 Settleability Experiments

Settleability tests similar to those performed at Lancaster were conducted on samples from storm events.

Initially, influent stormwater settling characteristics were determined for the 6/29/80 event. The wooden sleeve was then constructed in the 87 in. (221 cm) pipe and the effects of this installation on influent characteristics were again determined during the 10/3/80 event.

Swirl foul underflow sample collection for settleability analysis was added during the 10/25/80 event to aid in the determination of removal efficiencies. Results showed that materials were settling in the Swirl foul discharge line (solids concentrations were less than in the influent). In view of this problem, the discrete foul sampler intake was repositioned to within the swirl tank foul discharge port and collection of foul settleability samples was discontinued. (10/25/80 foul settleability results are not reported).

A further alteration to the wooden pipe sleeve within the 87 in. (221 cm) was made after the 10/25/80 event to improve influent flow velocity.

Three influent and clear settling column experiments were conducted on 6/9/81, 6/22/81 and 8/4/81 to ascertain suspended solids efficiency rates. When settleability experiments were simultaneously conducted on both the Swirl and the Helical Bend (6/22/81 and 8/4/81) samples were taken from influent waste streams and uniformly mixed.

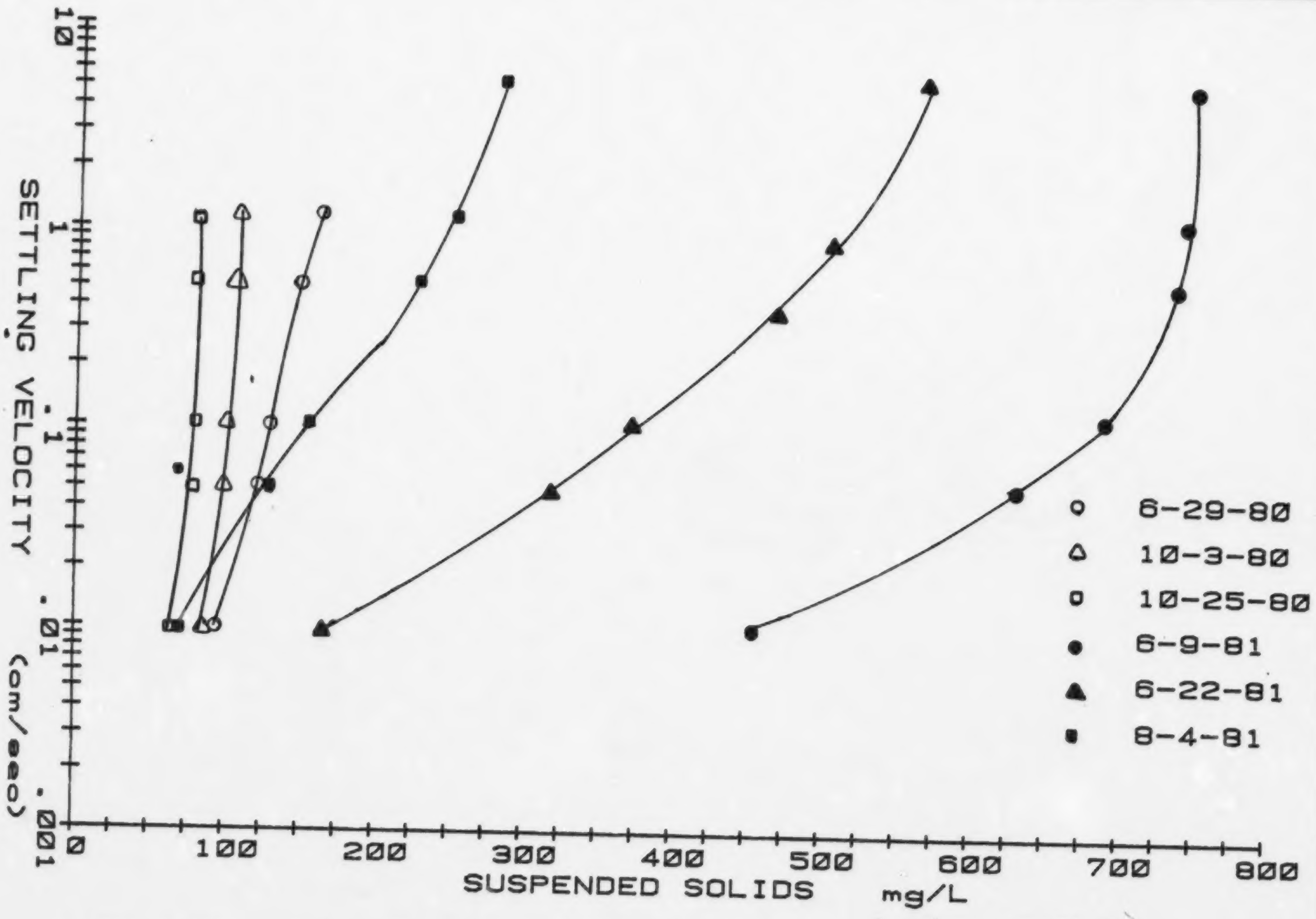
Analysis of influent settleability results are reported in section 13.4.1 in which a comparison of all influent settleability data is made. In section 13.4.2 of settling column analyses of influent vs. clear are presented for 6/9/81, 6/22/81 and 8/4/81 events. Overall suspended solids efficiency rates are computed from measured results and are compared with theoretical efficiency rates computed using the APWA results (4).

Section 13.4.1. Influent Settleability Characteristics

Figure 163 displays the influent suspended solids settleability curves for the 6 storm events sampled for settling column analysis at West Roxbury. Significant characteristics of the settleability curves demonstrated by simultaneous plotting are the range of initial concentrations (81 to 758 mg/l) and the varying percentages of solid fractions within settling velocity ranges. Data values for curves shown in Figure 163 and other pertinent related information are given in Table 19.

The wide range of concentrations seen among the curves is the result of four factors. First, average storm event flow rates varied between 1.2 and 12.3 cfs (34 and 348 l/s). Second, the wooden pipe sleeve was constructed within the 87 in. (221cm) pipe and then altered. Thirdly, fall events were impacted by filtering action of catchbasins clogged with leaves. Fourth, the presence of a quarry in the watershed discharging into the storm drainage system a variable amount of fine rock dust resulted in variable background solids concentrations.

Influent flow and initial settling column suspended solids from the 6/29/80 event (prior to the sleeve installation) yields a mass rate of 1.29 lb/min (.58 kg/min). After the sleeve installation a mass rate of 2.4 lb/min (1.1 kg/min) was recorded on 10/3/80. As the data shows the actual concentration of solids was less during the second event. The increased storm intensity and flow rate was sufficient to offset this decrease implying that the concentration decrease was due to dilution effects. The increased storm intensity would probably have added to the amount of material washed into the upstream end of the system and the new sleeve would have reduced settling in the influent line. The degree to which the mass rate increased due to each of these changes cannot be determined.



1 cm/s = 0.033 ft/s

Figure 163. Influent suspended solids settleability characteristics, W. Roxbury.

## TABLE 19

## INFLUENT SUSPENDED SOLIDS SETTLEABILITY ANALYSES SUMMARY

| Settling Velocity cm/sec | 6/29/80 Inf.Conc. mg/l | 10/3/80 Conc. mg/l | 10/25/80 Conc. mg/l | 6/9/81 Conc. mg/l | 6/22/81 Conc. mg/l | 8/4/81 Conc. mg/l |
|---|---|---|---|---|---|---|
| 5.0 | - | - | - | 758.0 | 544.0 | 283.0 |
| 0.9 | 155.0 | 104.0 | 81.0 | 750.0 | 490.0 | 250.0 |
| 0.5 | 148.2 | 103.0 | 79.8 | 748.0 | 470.0 | 225.0 |
| 0.1 | 131.0 | 99.5 | 75.7 | 685.0 | 375.0 | 155.0 |
| 0.05 | 120.1 | 94.2 | 73.4 | 635.0 | 320.0 | 125.0 |
| 0.01 | 93.6 | 80.3 | 60.3 | 450.0 | 163.0 | 61.0 |

| Event Key | A | B | B | C | C | C |
|---|---|---|---|---|---|---|
| Flow (cfs) | 2.2 | 6 | 4.5 | 1.2 | 2.2 | 12.3 |
| Col. Initial Conc. (mg/L) | 156 | 107 | 81.5@ | 759 | 552 | 283 |
| Mass Rate (lb/min) | 1.3 | 2.4 | 1.4 | 3.4 | 4.5 | 12.7 |
| Background Conc. (mg/l) | 93.6 | 80.3 | 60.3 | 450 | 180 | 61 |
| Adjus. Init. Conc. (mg/l) | 62.4 | 26.7 | 21.2 | 308 | 372 | 222<br>@@(359) |
| Adjus. Mass Rate lb/min | 0.5 | 0.6 | 0.4 | 1.4 | 3.0 | 10.0<br>@@@ (16.1) |
| Samp.Time for Sett. (min) | 0-15 | 0-20 | 0-15 | 45-55 | 0-20 | 0-7 |
| Discrete Samp. Conc. (mg/l) | 125 | 110 | 60 | 650 | 498 | 420 |

@* Low value due to leaves in catchbasins filtering flow
@@ Based on discrete sample concentrations
@@@ Based on discrete sample conc.less background conc.

A - Pre Sleeve/ B - Post Sleeve/ C - Post Sleeve Modification
1 cm/sec = 0.03 ft/sec; 1 cfs = 28.3 l/s, 1 kg/min. = 0.454 lb/min.

The next event on 10/25/80 included a moderate flow rate yet the mass rate was typical of pre-sleeve installation events. The low influent concentration was deemed attributable to leaf buildup in the catchbasins feeding the system. These accumulations tended to filter out much of the solids entering the catchbasin prior to the influent line.

After this event the catchbasins were cleaned and the wooden pipe sleeve was altered to increase the flow velocity. During the next two events on 6/9/81 and 6/22/81, low flow rates still produced high solids concentrations indicating good drainage area washout and minimal settling in the influent feed lines.

Flows were substantially higher during the last event monitored 8/4/81. The low solids concentration was due to dilution effects since the mass flow rate increased. Mass rates were based on settleability sample concentrations which were typically similar to discrete sample values with the exception of the 8/4/81 data as discussed below.

The shape of the influent settleability curves shown in Figure 163 for the three 1981 events sampled are dissimilar indicating that the percentages of solids at the various settling velocities varied during each of the events. Variations in total concentrations were caused by the presence of light weight solids materials causing a variable background concentration. Background material has been traced to a quarry dust residue entering the sewer above the facility from a local rock quarry in the West Roxbury area.

This fine material has a settling velocity less than that accounted for in the two hour settleability test, that is, 0.003 ft/sec (0.01cm/sec), yet greater than that roughly defined by the settleable solids determination test, that is, 1 x $10^{-5}$ ft/sec (0.003cm/sec). It is therefore not removed in the settling column but is considered settleable solids. Settleability sample background solids concentrations, loosely defined as the material with a settling velocity less than 0.003 ft/sec (0.01cm/sec) were 450mg/l for the 6/9/81 event, 180 mg/l for the 6/22/81 event and 61 mg/l for the 8/4/81 event, respectively.

Since the quarry material could be considered non-representative of typical stormwater loads, the column initial concentrations were reduced by these background values resulting in the adjusted initial concentrations and mass rates in Table 19. The adjusted influent solids concentration values are quite similar and the mass flow rates are nearly proportional to the flow rate for first two 1981 events. For the

8/4/81 event, similar mass rates can be derived by using solids concentration obtained from the discrete sampling (as opposed to the settling column sampling technique). As next explained, solids concentrations obtained by discrete sampling techniques are probably more reliable.

Comparison of these values to the shapes of the settleability curves indicates a certain trend. The 6/22/81 sample has the highest initial concentration. Of the three 1981 events these data also reflected the greatest amount of material with a settling velocity above 0.03 ft/sec (1.0cm/sec). The 6/9/81 event had a lower adjusted concentration and a low mass flow rate due to the low flow rate. This event also contained little or no material with a settling velocity above 0.03 ft/sec (1.0 cm/sec). The lack of material of this type is probably due to the effects of low flow on the degree of street washdown and settling within catchbasins. In addition, samples were collected late in the event when most heavy material may have already past through the system (see table 19).

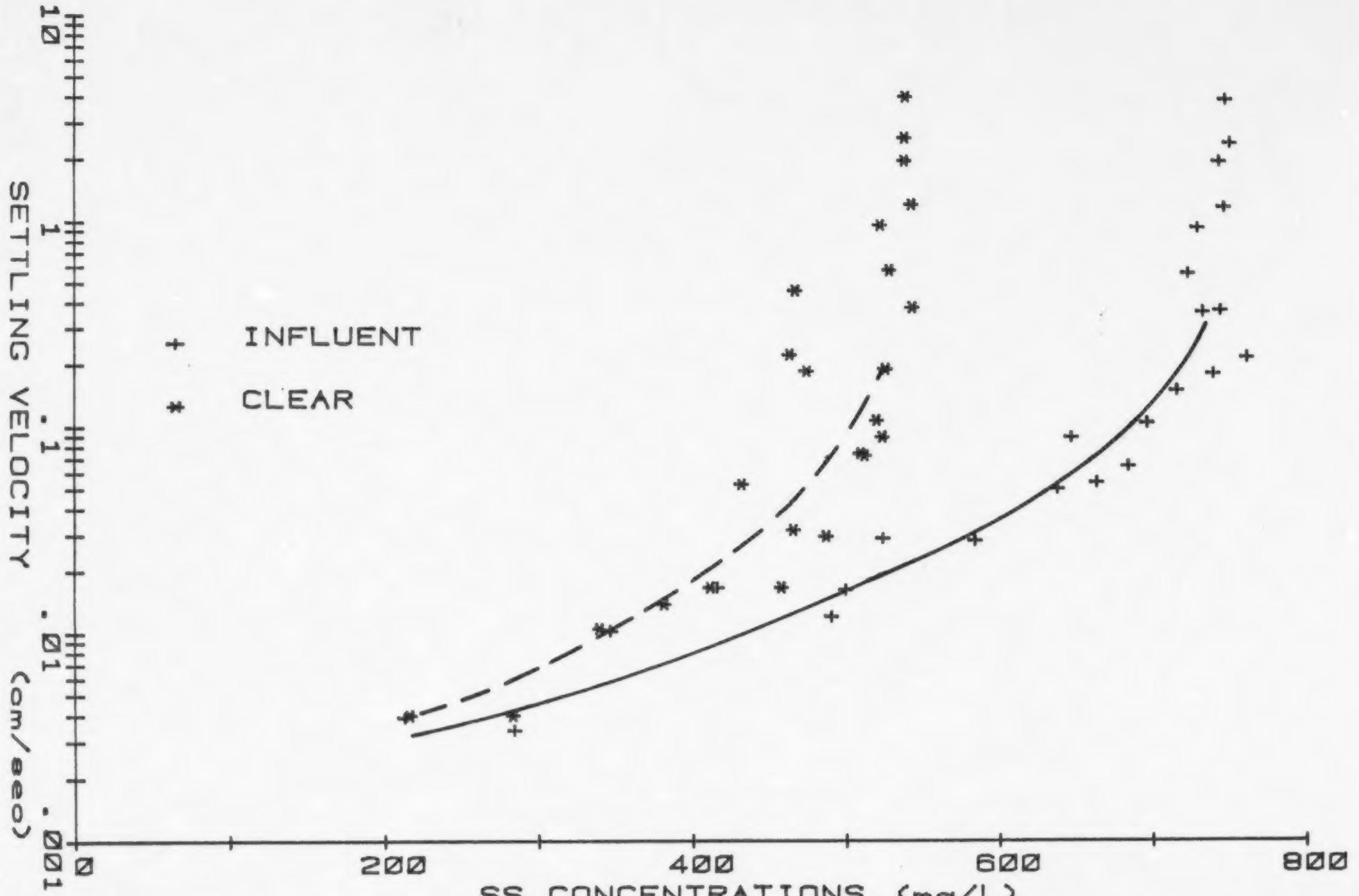
Data from the 8/4/81 event demonstrate half the material in the range above 0.03 ft/sec (1.0 cm/sec) as seen in the 6/22/81 event. Since the flow rate was six times as much the actual solids mass rates of materials above 0.03 ft/sec (1.0 cm/sec) were much higher. This would be expected considering that the higher flow rate of the 8/4/81 would produce a greater mass of solids of all sizes. In the case of the 8/4/81 data discrete sample concentrations were 1.5 times the settleability sample values. It is suspected that the methods used for large volume settleability sampling are limited in the ability to deliver representative samples. Discussion of sampling techniques and implications relating to settleability results are included in the next section.

It is evident from inspection of the suspended solids settling curves in Figure 163 that the stormwater solids contaminants from the urbanized watershed in West Roxbury, Boston generally have lower settling velocities than the "proposed" solids settling velocity curves used in the formulation of the Swirl Regulator/Concentration design documents (4) (see Figure 6, Chapter 4).

## Section 13.4.2 Efficiency determination using Settleability Results

### 6/9/81 Event

Figure 164 displays the influent and clear Swirl Concentrator settleability characteristics for the 6/9/81 event. Overall the 6/9/81 event indicated a suspended solids



1 cm/s = 0.033 ft/s

Figure 164. Influent and clear suspended solids settleability characteristics, W. Roxbury Swirl Concentrator/Regulator (6/9/81).

removal efficiency of 28.6% (calculations given in Table 20). The Swirl Concentration efficiency is 21.4% considering solids with settling velocities down to 0.015 cm/sec (0.003 ft/sec). The additional increment of 7.2% (indicated in Table 20) is attributable to the 55 mg/l differential associated with the lower end of the two settling velocity curves shown in Figure 164. The theoretical efficiency is 8.1% with calculations in Table 21. The low overall efficiency is due to the lack of removal (as expected) of the heavy background quarry solids concentrations. Since this material accounted for 60% of the initial solids the 28.6% actual overall removal could actually be stated as 71% removal of the non-background material.

Based on the breakdown of material by settling velocities seen in Table 20, no removals occured above 0.006 ft/sec (0.02 cm/sec) which indirectly implies that there was no material with settling velocities greater than this value in the influent flow. The fact that the plots in Figure 164 and in Table 20 indicate minimal material above this value is due to the "best curve" fitting techniques used. Due to limitations of sample mixing, sampling techniques and analytical techniques some variation in resultant solids values is expected. When the actual amount of solids in a certain range is similar to the typical variation, exact values cannot be determined. In the case of the 6/9/81 influent settleability sample it appears little or no material with a settling velocity greater than 0.006 ft/sec (0.02 cm/sec) was present. Possbile causes of this are discussed at the end of this section.

## 6/22/81 Event

Settleability tests for the 6/22/81 event include both Swirl Concentration and Helical Bend units. Figures 165 through 168 display the settleability characteristics of the suspended and volatile suspended solids for the Swirl and Helical Bend, respectively.

Swirl data indicate an overall removal rate of 4.5%. Efficiency calculations are provided in Table 22. If the two settling curves shown in Figure 165 coincided at the lower settling rates (less than 0.01 cm/sec or 0.0003 ft/sec) then the efficiency would be 22.5%. Based on the influent flow rate and solids concentrations the theoretical removal rate is 23.3%. (Table 23) For this event 10% of the influent solids had a settling velocity greater than 0.03 ft/sec (0.1 cm/sec) and it would be expected that the Swirl would remove almost all of this material.

Comparison of the Swirl influent and clear sample settleability curves indicates several irregularities. The

## TABLE 20

## SWIRL EFFICIENCY BASED ON SETTLEABILITY MEASUREMENTS, 6/9/81

Flow Rate = 1.2 cfs (34 l/s)

| Set. Vel. Region | Set.Vel. cm/sec | Inf TSS mg/l | Clear TSS mg/l | Inf. Conc. Change mg/l | Clear Conc. Change mg/l | * | ** | @ | @@ |
|---|---|---|---|---|---|---|---|---|---|
| | >5.0 | 758 | 540 | | | | | | |
| 1 | | | | 5 | 5 | 0.65 | 0.65 | 0 | 0 |
| | 4.0 | 753 | 535 | | | | | | |
| 2 | | | | 5 | 5 | 0.65 | 0.65 | 0 | 0 |
| | 0.51 | 748 | 530 | | | | | | |
| 3 | | | | 10 | 10 | 1.3 | 1.3 | 0 | 0 |
| | 0.18 | 738 | 520 | | | | | | |
| 4 | | | | 58 | 40 | 7.6 | 5.3 | 2.3 | 31.0 |
| | 0.09 | 680 | 480 | | | | | | |
| 5 | | | | 45 | 20 | 5.9 | 2.6 | 3.3 | 55.5 |
| | 0.05 | 635 | 460 | | | | | | |
| 6 | | | | 55 | 20 | 7.2 | 2.6 | 4.6 | 63.6 |
| | 0.03 | 580 | 440 | | | | | | |
| 7 | | | | 110 | 25 | 14.5 | 3.3 | 11.2 | 77.0 |
| | .015 | 470 | 415 | | | | | | |
| | | | | | | | | ----- | |
| | | | plus 7.2% Differential Below | | | | | 21.4 | |
| | | | 0.015 cm/sec (see Figure 164) | | | | | 7.2 | |
| | | | | | | | | ---- | |
| | | | | | | Actual Efficiency | | 28.6% | |

* % inf. conc. change relative to inf. starting cone.<br>
**% clear conc. change relative to influent starting conc.<br>
@% Removed of initial influent conc.<br>
@@% Removed within set. vel. region.

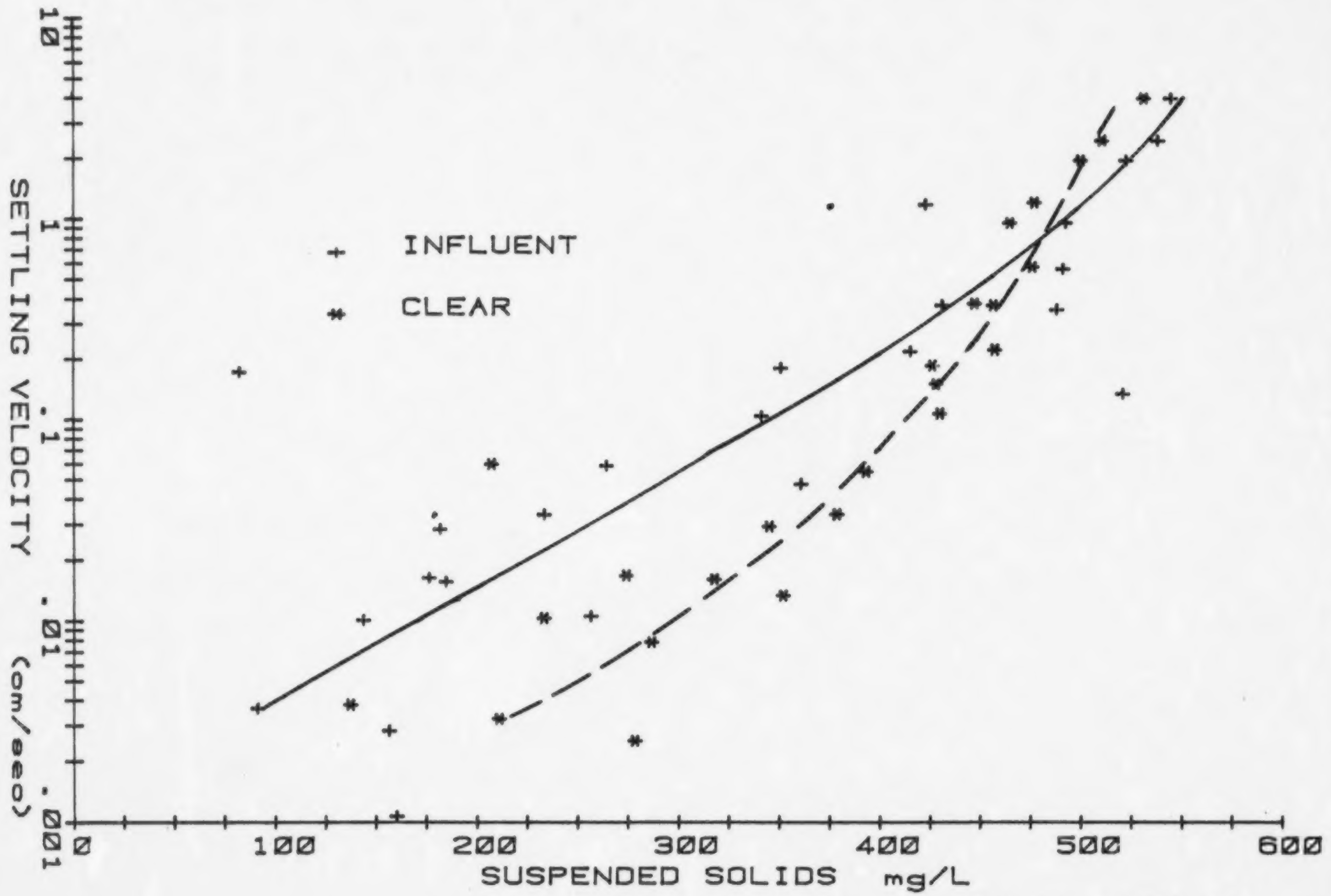
## TABLE 21

## THEORETICAL SWIRL EFFICIENCY, 6/9/81

flow rate of 1.2 cfs (34 L/s)

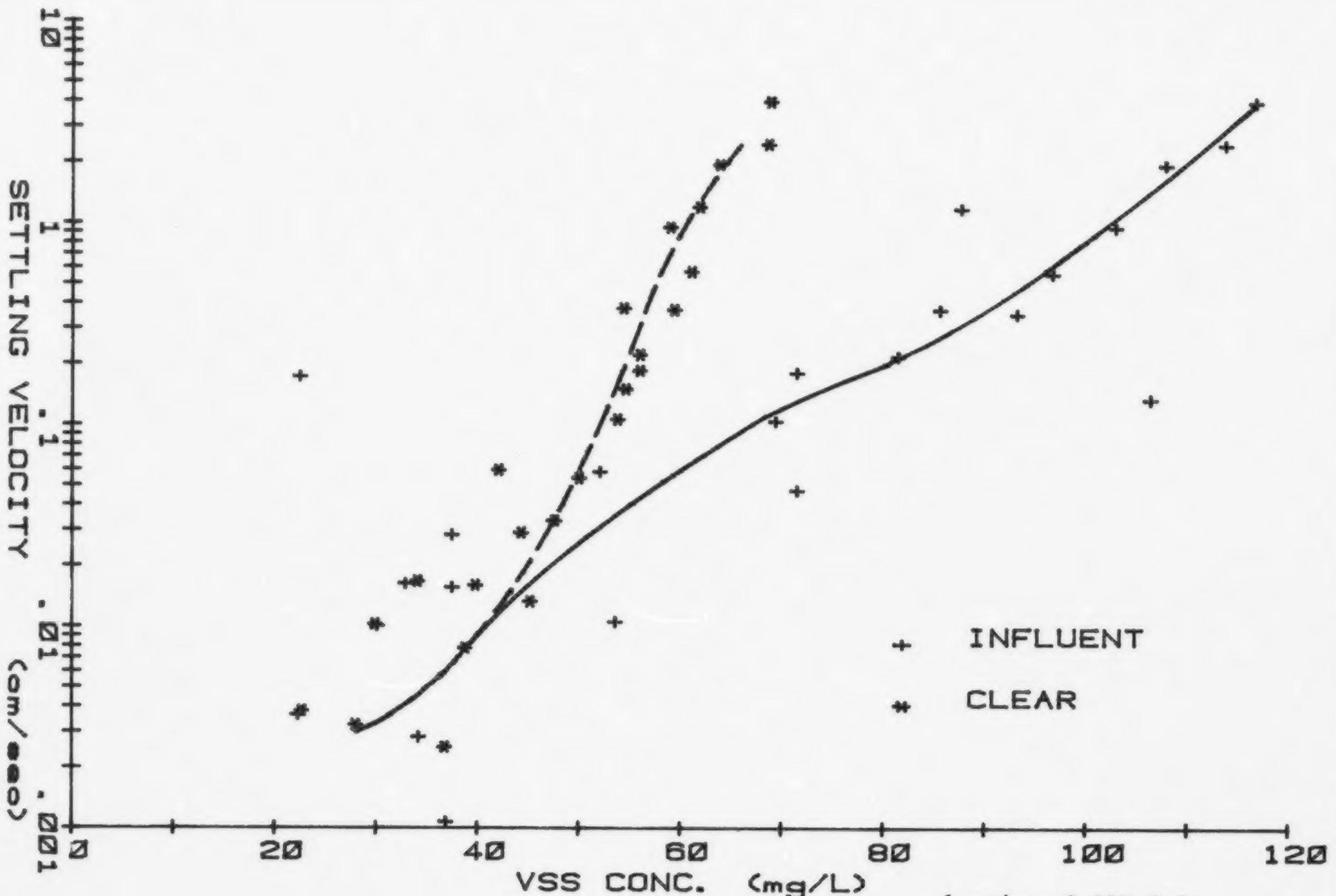
| Region | Sett.Vel. cm/sec | Inf. TSS Conc. mg/L | % of Total TSS in Region | Model Sett. Vel. cm/sec | Model % Rem. | Avg. % Removal in Region | % Rem in Region |
|---|---|---|---|---|---|---|---|
| | 7.5 | 758 | | 4.5 | 100 | | |
| 1 | | | 0.65 | | | 100 | 0.65 |
| | 4.0 | 753 | | 2.4 | 100 | | |
| 2 | | | 0.65 | | | 90 | 0.60 |
| | 0.51 | 748 | | 0.3 | 80 | | |
| 3 | | | 1.3 | | | 62.5 | 0.80 |
| | 0.18 | 738 | | 0.1 | 45 | | |
| 4 | | | 7.6 | | | 34 | 2.60 |
| | 0.09 | 680 | | 0.053 | 23 | | |
| 5 | | | 5.9 | | | 19 | 1.10 |
| | 0.054 | 635 | | 0.03 | 15 | | |
| 6 | | | 7.2 | | | 12.5 | 0.90 |
| | 0.03 | 580 | | 0.017 | <10 | | |
| 7 | | | 14.5 | | | <10 | 1.40 |
| | .015 | 470 | | 0.008 | <10 | | |
| | | | | | | Theoretical Efficiency | 8.1% |

1 cm/sec = 0.03 ft/sec



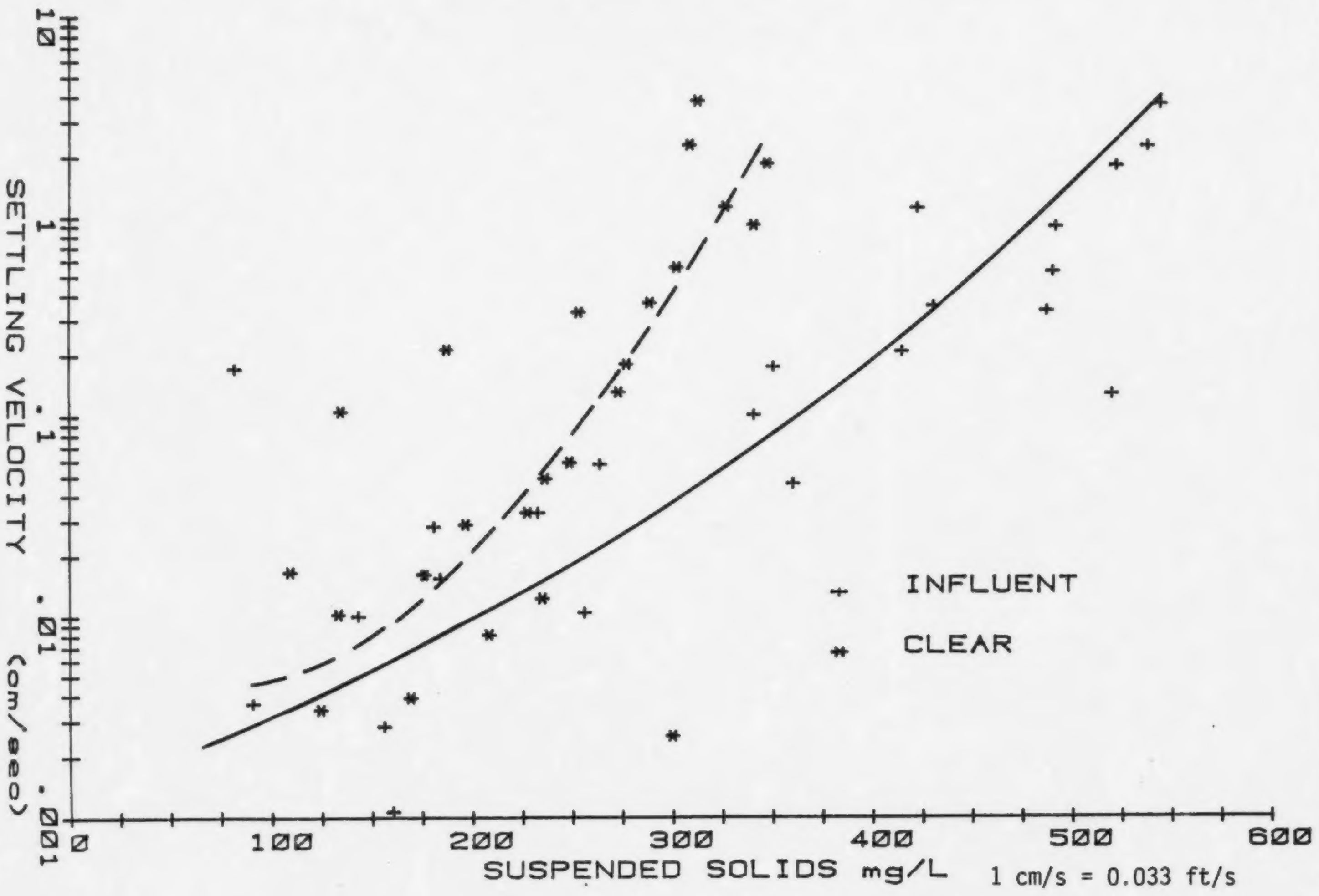
1 cm/s = 0.033 ft/s

Figure 165. Influent and clear suspended solids settleability characteriestics, W. Roxbury Swirl Concentrator/Regulator (6/22/81).



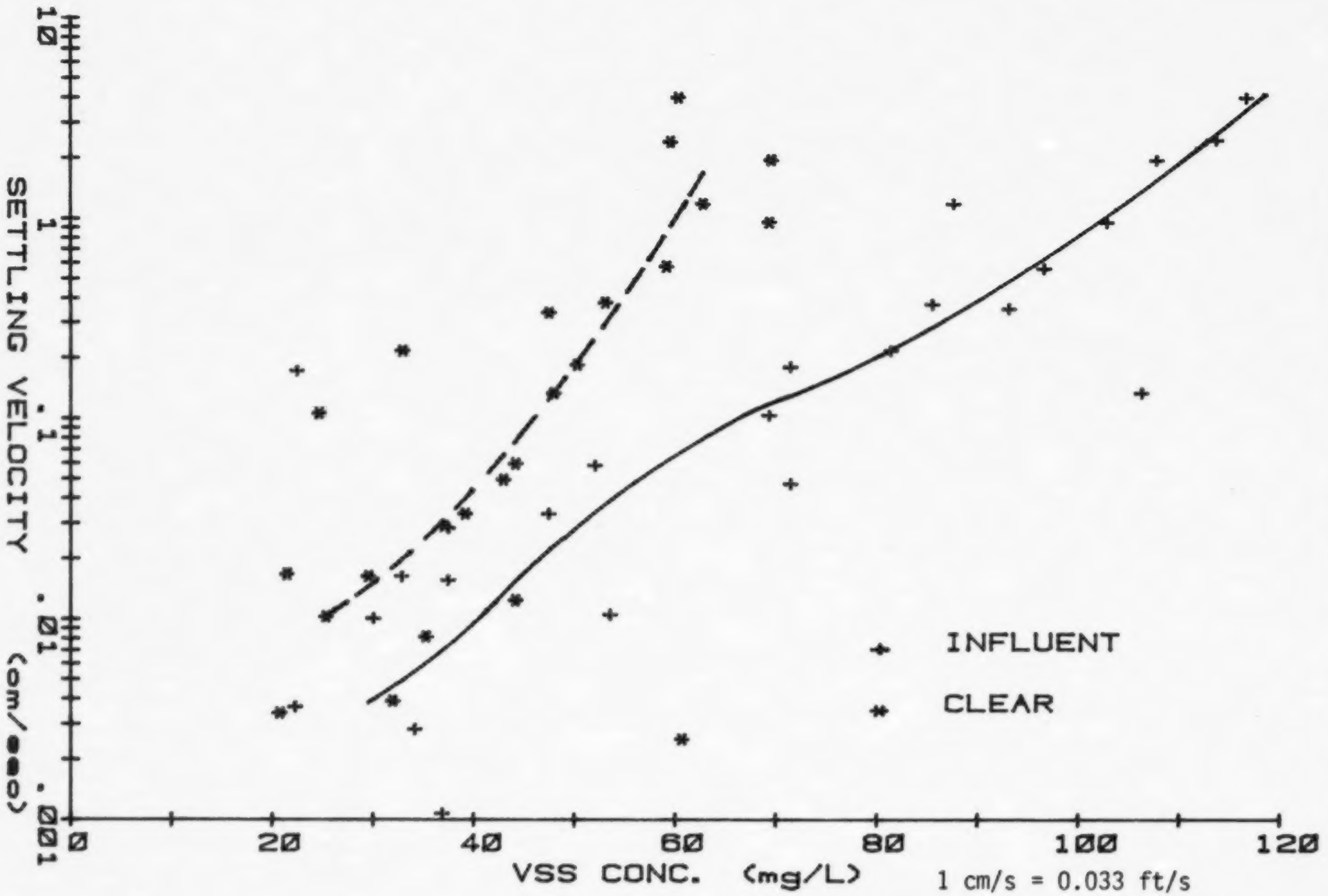
1 cm/s = 0.033 ft/s

Figure 166. Influent and clear Volatile suspended solids settleability characteristics, W. Roxbury Swirl Concentrator/Regulator (6/22/81).



1 cm/s = 0.033 ft/s

Figure 167. Influent and clear suspended solids settleability characteristics, W. Roxbury Helical Bend Regulator (6/22/81).



1 cm/s = 0.033 ft/s

Figure 168. Influent and clear volatile suspended solids settleability characteristics, W. Roxbury Helical Bend Regulator (6/22/81).

## TABLE 22
## SWIRL EFFICIENCY BASED ON SETTLEABILITY MEASUREMENTS, 6/22/81

flow rate = 2.2 cfs (62.3 l/s)

| Region | Set.Vel | Inf. TSS | Clear TSS | Inf. Conc. change | Clear Conc. change | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | cm/sec | mg/l | mg/l | mg/l | mg/l | * | ** | @ | @@ |
| 1 | 5 | 552 | 530 | | | | | | |
| | | | | 32 | 30 | 5.8 | 5.4 | .4 | 7 |
| 2 | 2 | 520 | 500 | | | | | | |
| | | | | 25 | 20 | 4.5 | 3.6 | .9 | 20 |
| 3 | 1 | 495 | 485 | | | | | | |
| | | | | 25 | 20 | 4.5 | 3.6 | .9 | 20 |
| 4 | .5 | 470 | 460 | | | | | | |
| | | | | 95 | 55 | 17.2 | 9.9 | 7.3 | 42 |
| 5 | .1 | 375 | 405 | | | | | | |
| | | | | 55 | 25 | 9.9 | 4.5 | 5.4 | 54 |
| 6 | .05 | 320 | 380 | | | | | | |
| | | | | 157 | 115 | 4.5 | 20.8 | 7.6 | 32 |
| 7 | .01 | 163 | 265 | | | | | | |

| | |
|---|---|
| -18% Differential Remaining Below. 01 cm/sec | 22.5%*<br>-18.0 |
| Actual Efficiency | 4.5% |

*% inf. conc. change relative to inf. starting conc.
**% clear conc. change relative to inf. starting conc.
@% removed of initial influent conc.
@@ % removed within sett. velocity region

## TABLE 23

## THEORETICAL SWIRL EFFICIENCY, 6/22/81

(flow rate 2.2 cfs (62.3 L/s)

| Region | Sett.Vel. cm/sec | Inf. SS Conc. mg/L | % of Total SS In Region | Model Sett. Vel. cm/sec | Model % Rem. | Avg. % Removal in Region | % Rem In Region |
|---|---|---|---|---|---|---|---|
| | 5 | 552 | | 2.8 | >100 | | |
| 1 | | | 5.8 | | | 97.0 | 5.8 |
| | 2 | 520 | | 1.1 | 94 | | |
| 2 | | | 4.5 | | | 86 .0 | 3.9 |
| | 1 | 495 | | .53 | 78 | | |
| 3 | | | 4.5 | | | 70.5 | 3.2 |
| | 0.5 | 470 | | .30 | 63 | | |
| 4 | | | 17.2 | | | 38 .0 | 6.5 |
| | 0.1 | 375 | | .053 | 13 | | |
| 5 | | | 9.9 | | | 11.5 | 1.08 |
| | 0.05 | 320 | | .03 | 10 | | |
| 6 | | | 28.4 | | | 10.0 | 2.8 |
| | 0.01 | 163 | | .0053 | 10 | | |
| | | | | Theoretical Efficiency | | | 23.3% |

1 cm/sec = 0.03 ft/sec

influent solids tend to have higher settling velocities than the clear sample material. Although the influent was initially more concentrated, the clear sample had a greater amount of solids within the lower settleability ranges. One possible explanation is the breakdown of larger particles within the unit.

Volatile fractions of the Swirl influent and clear samples were 21% and 13% respectively, implying an overall removal of 8% on a volatile basis alone. Given the overall removal rate of 4.5% there appears to have been a 3.5% increase in non-volatile material. Breakdown of larger particles would not account for this effect. This increase could be the result of solids accumulations within the Swirl unit.

Since there was a definite decrease in material with settling velocities greater than .06 ft/sec (2 cm/sec) the Swirl can be stated to be effective in this range. For this event 22% of this material was removed.

Simultaneously the Helical Bend provided an efficiency of 43% (see Table 24). The total overall efficiency rate noted in Table 24 is 42.9%. Above 0.01 cm/sec (0.003 ft/sec) the removals divided among the designated settling velocity regions on Table 24 total 34.2%. Below 0.01/sec settling velocity region the unit achieved an additional 8.7% removal efficiency (also see lower portion of two settling curves on Figure 167). Volatile fractions in the clear sample were nearly identical to those within the Swirl clear sample. Eight % of the organic material was removed implying 35% removal of inorganic material. There appeared to be minimal build-up of material in the unit during this part of the event. The highest removals occured in the highest settling velocity ranges although good removals were demonstrated in each range.

## 8/4/81 Event

Figures 169 and 170 display the Swirl Concentrator and Helical Bend influent and clear suspended solids settling curves. Inspection of these Figures indicate no removal based on the settleability analysis. Initial clear sample concentrations for both the Swirl and Helical Bend were higher than the influent sample.

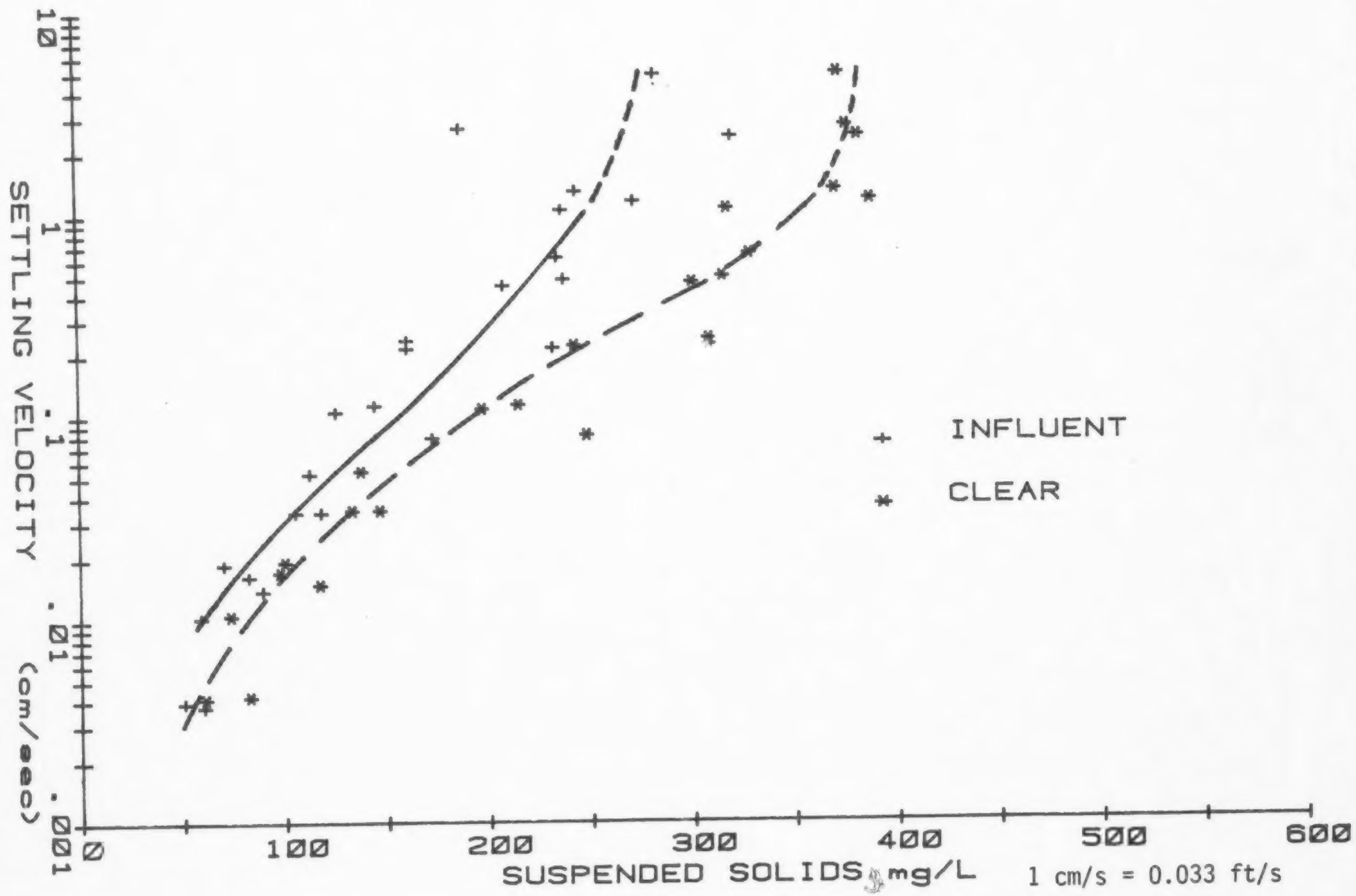
Considering the sampling techniques used, the data shown in Figures 169 and 170 can possibly be explained as follows. During past events flow rates were between one-tenth to one-half the 12 cfs (338 l/s) which occured during the 8/4/81 event. Settleability samples were collected in the influent line just downstream of the Palmer Bowlus flume where

## TABLE 24

## HELICAL BEND EFFICIENCY BASED ON SETTLEABILITY MEASUREMENTS
6/22/81

| Region | Set.Vel<br>cm/sec | Inf. SS Conc.<br>mg/l | Clear SS Conc.<br>mg/l | Inf. Conc. change<br>mg/l | Clear Conc. change<br>mg/l | * | ** | @ | @@ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 552 | 315 | | | | | | |
| | | | | 57 | 5 | 10.3 | 0.9 | 9.4 | 92 |
| 2 | 1 | 495 | 310 | | | | | | |
| | | | | 25 | 10 | 4.5 | 1.8 | 2.7 | 60 |
| 3 | .5 | 470 | 300 | | | | | | |
| | | | | 95 | 55 | 17.2 | 10.0 | 7.2 | 42 |
| 4 | .1 | 375 | 245 | | | | | | |
| | | | | 55 | 35 | 9.9 | 6.3 | 3.6 | 36 |
| 5 | .05 | 320 | 210 | | | | | | |
| | | | | 157 | 95 | 28.4 | 17.2 | 11.2 | 35 |
| 6 | .01 | 163 | 115 | | | | | ----- | |
| | | | | | | | | 34.2 | |
| | | | 8.7% Differential Remains Below. .01 cm/sec | | | | | 8.7 | |
| | | | | | | | | ------ | |
| | | | | Actual Efficiency | | | | 42.9% | |

* % Inf. conc change relative to inf. starting conc.
** % Clear conc. change relative to inf. starting conc.
@ % Removed of initial influent conc.
@@ % Removed within set. velocity range 1 cm/sec = 0.03 ft/sec



1 cm/s = 0.033 ft/s

Figure 169. Influent and clear suspended solids settleability characteristics, W. Roxbury Swirl Concentrator/Regulator (8/4/81).

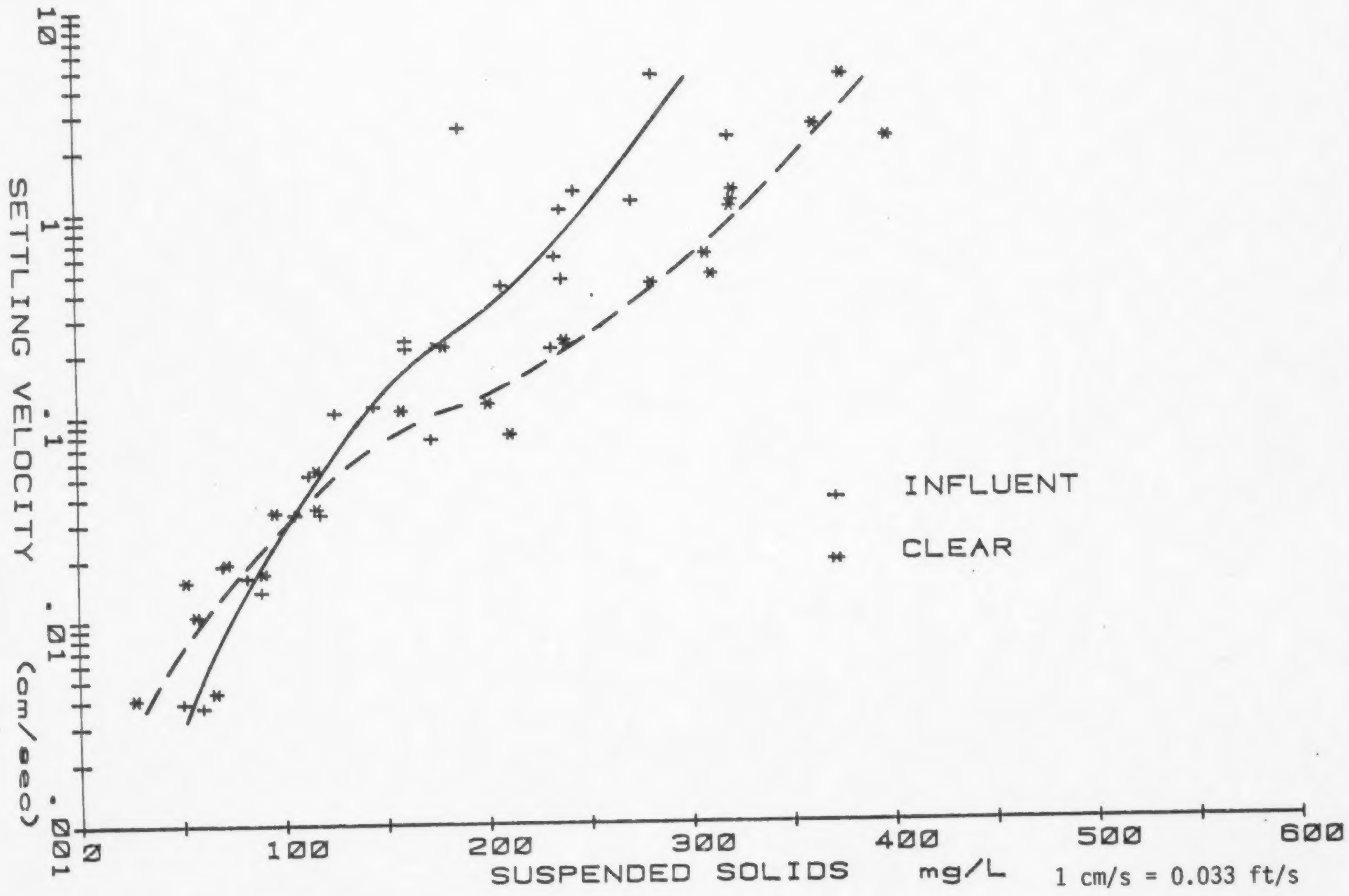


Figure 170. Influent and clear suspended solids settleability characteristics, W. Roxbury Helical Bend Regulator (8/4/81).

the flow depth was minimal. A four gal. (17.5 l) bucket was used to collect samples. Under previous storm conditions inserting the bucket to the invert of the influent line was no problem. During the 8/4/81 event the increase in flow depth and velocity appears to have acted to fill the sample bucket before it could be submerged to the influent line invert. Samples collected would thus not contain representative bed load materials Discrete samples were not affected by the increased flow and velocity as the methods used allowed complete submergence of l-l sample bottles. (Filling while raising the 1/l bottles tended to yield a more cross- sectional composite sample).

Comparison (see Table 19) of initial settling column suspended solids concentrations with concentrations of samples taken for discrete analysis (see section 13.3) indicates that for previous events discrete influent sample and settleable sample concentrations were similar. For the 8/4/81 event the influent discrete suspended solids concentration equalled 420 mg/l while the initial or starting concentration of the influent settling column test was 283 mg/l, much higher. If the settleability sample concentration had equaled the discrete sample concentration of 420 mg/l the Swirl efficiency would have been calculated to be 11% while the efficiency for the Helical Bend would have approached 20%.

## 13.5 Performance Summary

Table 25 summarizes the suspended solids performance data for the Swirl Regulator and Helical Bend units. Suspended solids efficiency rates are comparable for both units. Efficiency rates are low for both units and do not seem to be related to flow rate. It appears that both units are able to achieve a low degree of primary-type suspended solids removal of stormwater related contaminants.

## 13.6 Dye Studies

Several dye studies were performed on the Swirl unit during selected storm events. Times for the dye to complete one revolution for varying flow rates are as follows:

## TABLE 25
## Summary: West Roxbury Evaluation
## Suspended Solids Removal and Efficiency Rates

| Date | Flow cfs | Removal Rate % | Efficiency % | Settleability Results |
|---|---|---|---|---|
| | | Swirl Concentrator | | |
| 6-29-80 | 2.0 | 21.0 | 8.2 | * |
| 7-29-80 | 3.0 | 35.3 | 27.5 | |
| 10-3-80 | 6.0 | 36.0 | 32.0 | **,@ |
| 10-25-80 | 3.0 | 29.7 | 21.4 | *** |
| 6-9-81 | 0.8 | 34.0 | 2.75 | *** 21.4 - 28.6% |
| | 3.0 | 27.0 | 19.0 | |
| 6-22-81 | 2.2 | 27.0 | 16.0 | *** 4-5 - 22.5% |
| | 2.0 | 33.0 | 21.0 | |
| 8-4-81 | 6.0 | 9.5 | 5.5 | @ |
| | 12.0 | 5.8 | 5.7 | |
| | | Helical Bend | | |
| 6-29-80 | 1.5 | 23.0 | 6.0 | * |
| 7-29-80 | 2.5 | 36.5 | 26.5 | |
| 10-3-80 | 4.5 | 16.0 | 10.4 | * |
| 10-25-80 | 2.5 | 36.5 | 26.5 | ** |
| 6-9-81 | .8 | 41.2 | 10.0 | * |
| | .8 | 50.5 | 19.3 | |
| 6-22-81 | 2.0 | 25.5 | 13.5 | 34.2 - 42.9% |
| 8-4-80 | 6.0 | 31.0 | 27.0 | @ |
| | 12.3 | 10.0 | 8.0 | |
| | 6.0 | 12.9 | 8.9 | |

* Influent ** Influent & Foul *** Influent & Clear
@ Sampling problem 1 cfs = 28.2 l/s

| Date | Flow (cfs) | Time (sec)* |
|---|---|---|
| 4-4-80 | .8 | 150 |
| 7-29-81 | .9 | 139 |
| 4-4-80 | 1.0 | 135 |
| 6-22-81 | 1.5 | 90 |
| 4-4-80 | 2.2 | 74 |
| 8-4-81 | 12.3 | 10 |

* Time to circulate through unit for 1 complete revolution

Inspection of these results indicates that as the flow into the unit increased, the time for a complete revolution of the liquid is reduced. Flow into the Swirl was expected to enter the chamber tangentially at the inlet ramp and circulate throughout the unit from the bottom progressively working its way to the surface. Observations during dye studies indicate that the flow always rises immediately to the surface as it exits the inlet ramp and then circulates throughout the chamber.

A dye study was performed on the Helical Bend during the June 22. 1981 event with flow into the unit varying between 1.5cfs to 10cfs (42.5 l/s to 283 l/s). The purpose of the study was to visually observe the flow path in the unit during an event. Flow velocity measurements throughout the unit were not taken. All observations were of a visual nature. Nearly perfect plug flow conditions were observed.

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